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SCIENCE POLICY STUDY
BACKGROUND REPORT NO. 9

DEMOGRAPHIC TRENDS AND THE SCIENTIFIC AND ENGINEERING WORK FORCE

REPORT

PREPARED BY THE

OFFICE OF TECHNOLOGY ASSESSMENT

TRANSMITTED TO THE

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*Ranking Republican Member.
**Serving on Committee on the Budget for 99th Congress.

LETTER OF TRANSMITTAL

House of Representatives,
Committee on Science and Technology,
Washington, DC, September 19, 1986.

To the Members of the Science Policy Task Force:

The study commissioned for the Task Force from the Office of Technology Assessment on "Demographic Trends and the Scientific and Engineering Work Force" is hereby submitted for your consideration.

This study consists of two parts. The first part, analyzing the overall demographic trends and their relationship to the supply and demand of science and engineering manpower was completed in December 1985. The second part, which provides profiles at the level of five individual fields of science and engineering, was initiated as a result of our hearings in February 1986. During the course of those hearings, the question of the applicability of the general conclusions found in Part I to the individual disciplines in science and engineering arose, and we asked the Office of Technology Assessment to conduct an additional analysis along those lines. The result is found in Part II.

In our study of the past and future of American science policy we have sought to look well beyond the current budget problems and the debates associated with immediate needs and opportunities. This is particularly difficult to do in the field of science and engineering manpower studies, where it seems that each study is based on different assumptions, varying methods of data collection, and different specific questions of concern. We are therefore especially grateful to the Office of Technology Assessment for bringing together many of the relevant studies and pointing to the longer term trends and conclusions which can be extracted from that great variety of past studies.

OTA's work on this study was headed by Dr. Eugene Frankel, a former staff member with the Committee on Science and Technology. We are indebted to Dr. Frankel for the masterful way in which he researched, synthesized and presented the large amount of data on which this study is based. We particularly want to acknowledge Dr. Frankel's contribution because it was his last major scholarly contribution he made in the field of science policy before his untimely death in the Spring of 1986. For Part II of the Study, Ms. Lisa Heinz served as Project Director with the collaboration of Dr. Daryl Chubin, Senior Analyst. At the OTA the work on this study was supervised by Mrs. Nancy Nasmyth, head of the OTA's Science Policy Group. We are indebted, as well, to Mrs. Nasmyth and her other associates for the contribution which this study is making to our work.

We commend this study to the attention of the members of the Science Policy Task Force, to the attention of the members of the Committee on Science and Technology and of the House as a valuable contribution to the important issue of analyzing the supply and demand of scientific and engineering manpower in the light of long-term demographic trends.

MANUEL LUJAN, *Ranking Republican Member.*	DON FUQUA, *Chairman.*

LETTER OF SUBMITTAL

OFFICE OF TECHNOLOGY ASSESSMENT,
Washington, DC, December, 1985.

Hon. DON FUQUA,
Chairman, Committee on Science and Technology,
House of Representatives, Washington, DC.

DEAR MR. CHAIRMAN: Scientists and engineers represent only 3 percent of the national work force, but they are crucial to the Nation's effort to improve its economic competitiveness and national security. Their work makes possible advances in knowledge that improve the well-being of people all over the world.

This technical memorandum explores the effect that changes in the size and composition of the U.S. population may have on the science and engineering work force. The study was requested by the Science Policy Task Force of the House Committee on Science and Technology.

OTA concluded that while demographic trends are important and should be considered in thinking about future scientific output, they are not a controlling variable. The flexibility of the American education system and the adaptability of our scientists and engineers enable market forces and career choices to play a dominant role in balancing supply with demand. OTS also concluded that it is important to maintain and strengthen existing efforts to improve access to scientific and engineering careers for disadvantaged groups.

JOHN H. GIBBONS, *Director.*

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PART I

Executive Summary

The key role of the Federal Government in educating and assuring an adequate supply of scientists and engineers has been acknowledged since the close of World War II. Scientists (including social scientists; see figure 1) and engineers represent only 3 percent of the national work force, but are considered by many to be a crucial element in the Nation's efforts to improve its economic competitiveness and national security. The Office of Technology Assessment was asked by the Task Force on Science Policy of the House Committee on Science and Technology to examine the implications of long-term demographic trends for scientific and engineering personnel policy, and to consider as well the barriers to and future trends in the participation of women and minorities in scientific and engineering careers.

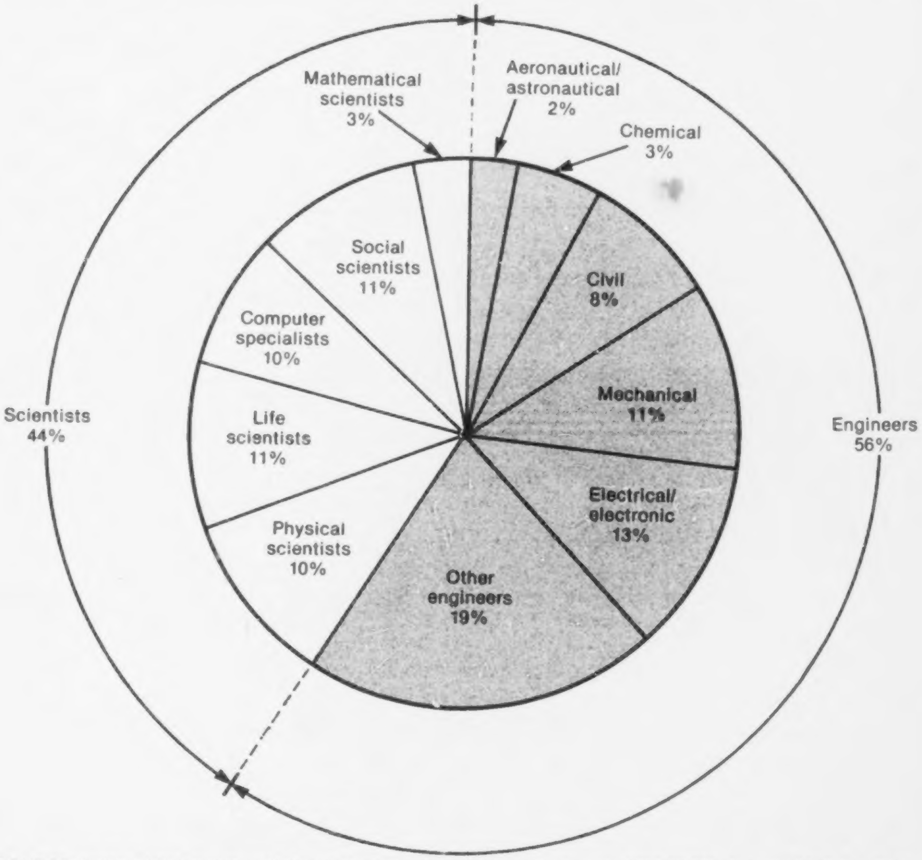
OTA found two significant demographic trends that could affect the supply of scientists and engineers. The first is a decline in the college-age population in the next decade. The number of 18 to 24 year olds will drop from a peak of 30 million in 1982 to about 24 million in 1995, or by 22 percent. Labor market specialists estimate that the decline in 18 to 24 year olds could lead to a drop in college enrollments of 12 to 16 percent between now and 1995.

Second is an increase in the fraction of the 18 to 24 year old cohort that will be drawn from minority populations, including blacks, Hispanics and Asian-Americans. These groups, with the exception of Asian-Americans, have historically participated less actively in science and engineering education than whites.

Science and engineering baccalaureates have constituted 28 to 32 percent of the total number of bachelor's degrees awarded in every year since 1952 (about 300,000 have been awarded annually in science and engineering since 1972). If this historical ratio continues, the expected drop in college enrollments and changes in the student mix would lead to a decline in the number of scientists and engineers being produced by the Nation's higher education system. If, as has been argued, the Nation will require an increasing number of scientists and engineers to meet its national security, economic growth, and technological innovation requirements, this possible decline in science and engineering baccalaureates could pose a significant problem. Fortunately, OTA finds this scenario to be unconvincing.

It is entirely possible that the supply of people trained in science and engineering will not decline at all, despite the drop in the college age population. This is possible for several reasons. First, the decline in enrollment

Figure 1.—Population of U.S. Scientists and Engineers by Field, 1983



SOURCE: National Science Foundation, *Science and Technology Resources*, NSF 85-305, January 1985, pp. 53-65.

may not be as severe as predicted. The proportion of 25 to 44 year olds who attend college, and whose population cohort will not be decreasing, has increased dramatically in the past decade, especially among women. The number of foreign nationals attending U.S. colleges and universities has increased more than tenfold in the past 30 years. If increases of 25 to 44 year olds and foreign nationals continue over the next decade, they could compensate, in part, for the decline in the number of 18 to 24 year olds.

Second, there could be increases in the rate at which college students choose to major in science and engineering. Less than 7 percent of the members of a given age cohort currently receive a bachelor's degree in a science or engineering field. This is near the low point of the last decade. A slight increase in the rate of selection of science and engineering careers among college age students could more than compensate for the decline in 18 to 24 year olds projected for the 1982-95 time frame. For example, if the rate of attainment of science and engineering bachelor's degrees were to increase from the 1982 level of 6.8 percent of the 22 year old population to the 1973 level of 8.2 percent that would cause a rise in the number of degrees awarded in these fields of 20 percent, which would exceed the projected demographic decline. Projections of shortage might well serve to increase science and engineering enrollments, as the labor market responds by promising increased pay or better job opportunities.

Third, science and engineering workers can be obtained by employing a higher proportion of those obtaining the required undergraduate degrees, and drawing on the existing talent pool. Less than two-thirds of the science and engineering baccalaureates produced in recent years have actually become part of the science and engineering work force.

Finally, on the graduate level, there appears to be no direct relationship between the number of Ph.D.s in science and engineering, and the size of the graduate school age population. Between 1960 and 1970 the number of full-time graduate science and engineering students enrolled in U.S. institutions of higher education increased 150 percent, and the number of science and engineering Ph.D.s awarded increased 183 percent. At the same time the population of 22 to 34 year olds—the group which supplies the majority of graduate students—increased only 18 percent. Between 1970 and 1983, by contrast, science and engineering enrollments increased by only 36 percent and annual doctorates awarded by 1 percent, but the 22 to 34 year old population increased by more than 50 percent. **Accordingly, the reduction in the size of the college-age cohort does not inevitably lead to a reduced supply of scientists and engineers.**

There is no national market for scientists and engineers as a group. Rather, there are specific markets for graduates trained in particular disciplines, and these markets and disciplines can experience very different conditions at the same time. For example, the National Science Foundation (NSF) projected in 1982 that the demand for electrical and aeronautical engineers and for computer specialists could exceed the supply of graduates in those fields by as much as 30 percent over the next 5 years, while at the same time there would be significantly fewer openings for biologists, chemists, geologists, physicists, mathematicians, chemical, civil, and mechanical engineers than there would be trained degree-holders. **Thus, it is individual disciplines, especially those linked with high growth or defense-oriented industries, that could experience personnel problems in the future; not "science and engineering" as a whole.**

This finding is encouraging, because individual disciplines have shown great ability to grow and shrink as market conditions require. The number of engineering baccalaureates, for example, more than doubled between 1976 and 1984. The number of bachelor's degrees in computer and informational science tripled between 1977 and 1982. At the same time, those in education, foreign languages, anthropology, history, and sociology all fell by 30 percent or more. Thus, college students appear to be highly responsive to market signals, and appear to shift their career choices dramatically toward fields that promise greater occupational rewards. **OTA concludes that career choices and market forces have a greater impact on the supply of scientists and engineers than do demographic trends.**

The possible decline in student enrollments discussed above, coupled with a low retirement rate among current faculty (most of whom were hired in the late 1960s and will not retire until the late 1990s), will lead to a very weak academic market for new Ph.D.s in the next decade. Studies carried out by a number of analysts in the late 1970s and early 1980s found that the annual demand for new junior faculty in the decade between 1985 and 1995 would fall to less than half of the levels experienced in the early 1970s. The annual academic demand for new science and engineering Ph.D.s could fall to as low as one-third the rate of hiring experienced in the 1970s during the 1985-95 time period. In the late 1990s the academic requirements for new junior faculty in general, and for new Ph.D. scientists and engineers in particular, should increase substantially, due to increases in both enrollments and retirements. In both cases the demand will most probably return to the levels experienced in the early 1970s and remain there through the first decade of the 21st century. The pattern of decline followed by increase will be experienced separately over the next quarter century by each of the major science and engineering fields. Although these patterns are generally acknowledged by experts in the field, considerable additional research is required to resolve uncertainties in the input assumptions to the projections—enrollments, retirements, resignations, tenure rates, and others. The consensus of experts is that **a combination of faculty and student demographics will lead to a weak academic market for new Ph.D.s over the next decade, followed by an upsurge in academic hiring between 1995 and 2010.**

In industry the demand for Ph.D. scientists and engineers has been strong for the past decade. If it should continue strong through the next decade, it could compensate for the decline in the projected academic demand. By the year 2000 industry and academia could be in stiff competition for new science and engineering Ph.D.s.

Apart from academia, however, where known demographic trends exert considerable influence, projections of supply and demand for scientists and engineers in the overall economy are fraught with uncertainty and are relatively unreliable. Such projections depend on assumptions about the future behavior of variables such as gross national product (GNP) growth, defense spending, technological change and Federal and industrial R&D expenditures, which themselves are not known with any degree of certainty. There is, moreover, no validated model that can reliably predict the career choices of undergraduates or graduate students, or their responsiveness to changes in demand in technical fields. In the absence of such a model, analysts have in the past tended to assume the continuation of existing trends, an assumption that can lead to gross inaccuracies. **Given the problems with forecasting supply and demand for scientists and engineers, predictions of shortages based on such forecasts should be treated with considerable skepticism.**

Most projections of shortages assume tacitly that demand and supply are independent, so that there can be no adjustment to supply-demand gaps. This assumption makes sense, however, only under certain *very restrictive* conditions:

1. that demand for the final product is relatively unaffected by labor costs;
2. that supply is not appreciably affected by wage changes; and

3. that the skill shortages are unique, in that workers possessing them cannot be replaced by workers from other occupations or by new technology.

If *any* of these conditions are violated, then a projected supply-demand gap will be closed by market adjustment. On the supply side, an increasing number of entry-level professionals can become trained in the shortage area, or experienced workers from neighboring specialties can move into the shortage occupation. On the demand side, employers can offer higher salaries, increase their search and recruiting efforts, rearrange jobs to utilize available skills, education and experience more efficiently, or make larger investments in training and retraining of their existing work force. **It is more important to try to understand the process of adjustment of the technical labor market to supply-demand imbalances than it is to make long-term projections.**

On the supply side, we have seen that students shift their career interests to follow signals from the marketplace. However, this response is not a short-term remedy to a supply-demand gap because it takes 4 years to train a new engineer and 6 years (from the baccalaureate) to train a new scientist in the university. In a fast-moving market, the needs of employers may change by the time entering students graduate.

Occupational mobility from related fields is the short-term response to shortages. The primary concern about occupational mobility from the employer's point of view is that it may lower the quality of work or lead to expensive retraining. From a societal point of view, however, occupational mobility appears to have served the Nation well in meeting its needs for technical personnel. The Manhattan project in World War II, the Apollo program in the 1960s, the environmental and energy programs of the 1970s and the rapid buildup of the semiconductor and computer industries all relied successfully on the importation of scientific and technical talent from related fields. Many analysts consider the mobility and adaptability of the Nation's scientific and engineering work force to be one of its greatest strengths.

Spot shortages among experienced scientists and engineers with specific areas of expertise, as have been reported in surveys of electronics and computer firms, are probably inevitable. When a new technology is developed it simply takes time before there is a pool of technically trained personnel who are experienced with the new techniques. There is no way to speed up this process more than minimally. The government could possibly help by taking a more active role in promoting the retraining of experienced engineers. Mission agency research and development programs in rapidly growing fields could possibly be modified to serve a retraining function. Apart from such assistance, however, **the government role in alleviating shortages of scientists and engineers appears quite limited.**

OTA finds that the changing college student demographics of the coming decade have several important implications for national policy to promote equality of opportunity in science and engineering. If the number of college graduates declines, it becomes especially important to utilize all potential human resources to the fullest extent possible. This means that increasing attention should be paid to those groups with historically weak participation rates in science and engineering, such as women and some minorities. The increasing fraction of college students that will be drawn from the black and Hispanic populations, which have historically participated in science and engineering education and employment at far lower rates than the white population, imply that programs aimed at increasing the participation of these two minority groups could be an especially important source of new talent. Thus, **near-term demographic trends underline the importance of promoting equality of access to scientific and engineering careers for women and disadvantaged minorities.**

Two factors stand out as crucial impediments to women's participation in science and engineering careers. The first is gender-stereotyped career expectations among younger women entering the science and engineering talent pool. These are manifested most dramatically in the major field preferences of college freshmen, where 20 percent of the men surveyed in 1984 but only 3 percent of the women, listed engineering as their field of choice. By contrast, only 4 percent of the men, but 21 percent of the women, listed education, nursing, or occupational and physical therapy as their preferred major. It appears that fields that are heavily associated with "men's work" tend to be avoided by women, just as fields that are stereotypically associated with women are avoided by men.

Girls' expectations of how they will be able to allocate their time during adulthood between participation in the labor force and work in the home also affects their career decisions. One analyst found that the more girls expect continuous labor force participation during adulthood, the more their occupational goals approximate those of their male counterparts. She also found that *male* single parents make occupational and labor force adaptations to parenting that look like the occupational and labor force plans of young women who expect dual family and work responsibilities. As long as women expect to assume the major role in housekeeping and childrearing, and to sacrifice their professional interests to those of their husband, they will be less likely than men to select occupations like science and engineering that require major educational and labor force commitments.

The second principal factor discouraging women from pursuing scientific and engineering careers is their differential treatment in the work force. Women's attrition rates from scientific and engineering careers are 50 percent higher than men's and their unemployment rates are more than double. Women's salaries are significantly lower than men's in almost all fields of science, in every employment sector and at comparable levels of experience. In academia men are far more likely than women to hold tenure-track positions, to be promoted to tenure and to achieve full professorships, even when academic age, field, and quality of graduate school attended are controlled for.

The differential treatment of women in the work force is thought by some to be the most serious violation of the principle of equality of opportunity because it affects people who have established, by virtue of obtaining an advanced degree, the right to pursue a scientific or engineering career based solely on the quality of their work. It also has a significant discouraging effect on female students in the educational pipeline, who see the future benefits of their investment in science and engineering education eroded by potential unemployment and underutilization in the work force. In sum, **gender-stereotyped career expectations and differential treatment of women scientists in the work force are the two major factors discouraging women from entering science and engineering.**

Among the minority groups that have been historically underrepresented in science and engineering, blacks, Hispanics, and American Indians receive degrees in quantitative fields at less than half the rate of whites, reflecting both lower participation in higher education and a lower rate of selection of quantitative fields. The causes of this underrepresentation are not well understood and could benefit from additional research. The quality of academic preparedness in secondary schools is cited by many experts as the greatest factor affecting these minorities' academic performance and baccalaureate attainment in college. Academic preparedness, however, appears to be related to socioeconomic factors such as parents' educational levels and social class. According to one study, the difference in the choices of quantitative majors across racial and ethnic groups are eliminated when the person is the second generation of a family to attend college. Social class, according to the same study, seems to be a proxy for a variety of family characteristics that affect school achievement, including the family's stress on achievement, language models in the home, academic guidance provided by the home, work habits and activities of the family, and the nature and quality of toys and games available to the child. They correlate very highly with children's achievement scores.

Despite the formidable socioeconomic problems responsible for the low participation rates in science and engineering among blacks, Hispanics, and American Indians, there is considerable evidence that well-designed intervention programs can assist these groups in obtaining access to science and engineering careers. To date these programs for minorities have not been rigorously and systematically evaluated to determine the ingredients of success and failure. Nor has any attempt been made to expand the coverage of the more successful programs. NSF was mandated by Congress to take a leadership role in this area, but thus far it has not done so. However, it appears safe to conclude that **the socioeconomic factors that lead to poor academic performance and an inability to remain in the science and engineering "pipeline" among blacks, Hispanics, and American Indians can be compensated for, to some degree, by well-designed intervention programs.**

Finally, OTA examined the increasing participation of foreign nationals in U.S. science and engineering education, which has raised a number of unresolved policy issues. The number of foreign nationals enrolled in American institutions of higher education has increased by a factor of 10 in the past three decades. Foreign students tend to enroll proportionately more often in engineering and medical sciences, and less in humanities and social sciences. They have assumed a very large share, 25 to 45 percent, of enrollments and doctoral degrees in graduate departments of engineering, physics, mathematics, and computer science, at the same time that the enrollment of American students in those departments declined.

There is concern that because science and engineering education is capital-intensive, and because many science and engineering graduate students are supported by Federal research assistantships, the United States is subsidizing the training of non-U.S. citizens. However, recent analysis indicates that foreign degree recipients appear to contribute more than the full cost of their education to their host institution. In addition there are foreign policy and goodwill benefits to the United States from the education of foreign citizens. It also appears that many graduate engineering departments would have had to curtail their research activities substantially without foreign graduate students.

There is disagreement as to whether individuals admitted to the United States as students who complete a graduate degree here should be allowed to remain here to accept employment. Many employers say that they cannot fill certain research and faculty positions without foreign nationals. Some professional societies, on the other hand, contend that U.S.-educated foreign engineers are taking jobs at lower pay in order to remain in this country, thus driving down salaries and reducing opportunities for U.S. engineers.

Several authors have made reference to a "growing problem" of foreign nationals on engineering faculties. They contend that the drawbacks of an increasingly foreign born faculty are limitations in their communications skills and difficulties they may have in adjusting their teaching and research styles to the expectations of American culture. Other observers note that foreign nationals may be unable to work on industry or government projects with national security or economic competitiveness implications. The validity of these assertions has yet to be documented.

The situation with respect to foreign nationals can best be summarized by saying that **although foreign nationals represent a large and growing fraction of science and engineering Ph.D.s, there is considerable disagreement over whether this constitutes a problem.**

In general, there does not appear to be convincing cause for concern that demographic trends will lead to shortages of scientists and engineers. The labor market for technical personnel has a variety of mechanisms for adjusting to potential supply-demand imbalances, and these appear to work reasonably well, without any great need for government intervention. However, the decline in the numbers of college graduates available for scientific and engineering careers in the next decade makes it increasingly important that all potential resources for the scientific and engineering work force be utilized to the fullest extent possible. For this to happen, the problems experienced by women, blacks, Hispanics, and other disadvantaged groups in entering scientific and engineering careers will have to be better understood and addressed.

Chapter 1: Overview and Findings

BACKGROUND AND RATIONALE FOR THIS STUDY

The key role of the Federal Government in educating and assuring an adequate supply of scientists and engineers has been acknowledged since the close of World War II.[1] It was reemphasized in a series of reports from the President's Science Advisory Committee in the immediate post-Sputnik (1958 to 1962) era which, according to one analyst,[2]

> . . . articulated the national need for greater numbers of scientists and engineers . . ., and for stronger federal support for the training of manpower for basic research and for university level teaching.

The current Administration has reaffirmed the Federal commitment to the education and training of scientists and engineers, stating that:[3]

> . . . we have to make sure that we derive educational and training advantages from federally supported research—because all of our expectations and opportunities for industrial progress call for a growing supply of skilled technical personnel.

The Task Force on Science Policy of the House Committee on Science and Technology finds that "many of the changes in educational and manpower demands are related in a significant way to general developments in the rates of birth and retirements." It believes that "these broad, demographic changes, if prudently used in connection with other data, might well provide insights that help anticipate future changes in enrollments and related developments."[4] To better understand whether demographic trends could be used to help anticipate changes in the requirements for education and training of scientists and engineers, the Committee asked OTA to carry out a study of "Demographic Trends and the Scientific and Engineering Work Force." As part of that study the Task Force on Science Policy recommended that OTA examine the effects of the "growing interest on the part of women and minorities" in pursuing scientific careers and the "barriers to such participation and the means for lowering them."[5] This report is presented as OTA's response to the Committee's request, and as its contribution to the national dialog on this important aspect of Federal science policy.

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[1] See Henry A. Moe, Chairman, "Report of the Committee on the Discovery and Development of Scientific Talent," in Vannevar Bush, *Science—The Endless Frontier*, Office of Scientific Research and Development (Washington, DC: U.S. Government Printing Office, July 1945), pp. 135-186.

[2] Susan Fallows, "Federal Support for Graduate Education in the Sciences and Engineering," background paper prepared for the Ad Hoc Committee on Government-University Relationships in Support of Science, National Academy of Sciences, 1983, p. 5.

[3] U.S. Congress, House, "Testimony of Dr. George A. Keyworth, Director, Office of Science and Technology Policy, Executive Office of the President," *1983 Science and Technology Posture Hearing With the Director of the Office of Science and Technology Policy*, Committee on Science and Technology, 98th Cong., 1st sess., Feb. 3, 1983 (Washington, DC: U.S. Government Printing Office, 1983), p. 15.

[4] U.S. Congress, House, *An Agenda for a Study of Government Science Policy*, report by the Task Force on Science Policy, Committee on Science and Technology, 98th Cong., 2d sess., Serial MM (Washington, DC: U.S. Government Printing Office, 1985), p. 30.

[5] Ibid., p. 31.

THE SCIENCE AND ENGINEERING WORK FORCE

Scientists and engineers represent 3 percent of the national work force, but are considered by many to be a crucial element in the Nation's efforts to improve its economic competitiveness and national security. Professor Karl Willenbrock of Southern Methodist University expressed this sentiment quite vividly in hearings on "Scientists and Engineers: Supply and Demand" before the Science Policy Task Force of the House Committee on Science and Technology:[6]

> The nation's economic vigor and quality of life, as well as military security, are strongly dependent on the number and quality of the engineers and scientists which the U.S. has available both now and in the future. Thus, the health and well-being of the system which educates American youth in engineering and science, and enables the practicing engineer and scientist to stay at the forefront of rapidly developing fields of science and technology is a crucial part of the nation's science policy.

Employed scientists and engineers numbered 3.5 million in 1983, an increase of 50 percent from 1976. During that same period the national employed labor force only increased by 11 percent. The scientific and engineering work force is quite heterogeneous in its composition. Fifty-six percent of the total are engineers, predominantly electrical and electronic engineers (13 percent); mechanical engineers (11 percent); and civil engineers (8 percent). The remaining 44 percent are scientists, 11 percent each in the life and social sciences; 10 percent in the physical and computer sciences; and 13 percent in the mathematical sciences. Figure 1-1 presents the breakdown of the science and engineering work force by field. Among the scientists, one in five has completed the full doctoral training that is generally considered necessary for a research career. Nearly half hold only a bachelor's degree and a third have been educated to the master's level. Engineers are even more heavily concentrated at the bachelor's and master's level, as can be seen in figure 1-2.

More than 80 percent of the Nation's engineers are employed in business and industry, with 12 percent in government and only 3 percent in education. The scientists are somewhat more evenly distributed among the three employment categories, with 51 percent in business and industry, 17 percent in government, and 24 percent in educational institutions (see figure 1-3 for more details). Eighteen percent of the scientists, but only 4 percent of the engineers, list research as their primary work activity. Thirteen percent of the scientists, but only 2 percent of the engineers, list teaching as their primary activity. Development, by contrast, is the principal work activity of 30 percent of the engineers but only 9 percent of the scientists (see figure 1-4).[7]

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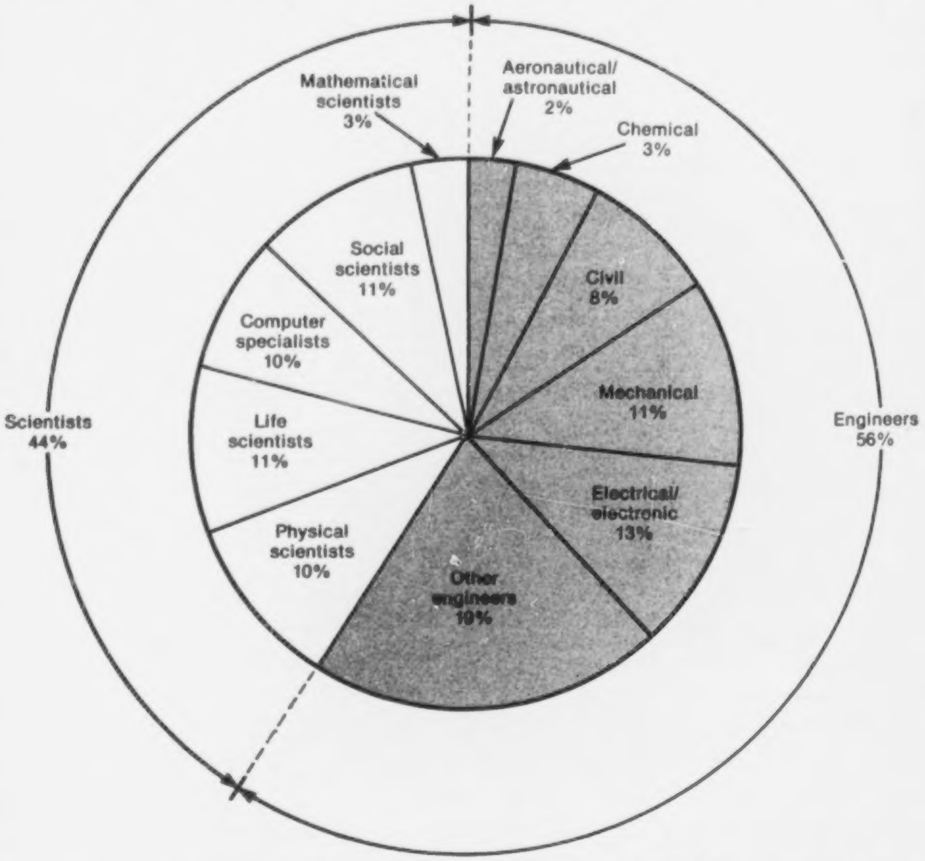
[6] U.S. Congress, House, "F. Karl Willenbrock, Testimony," Committee on Science and Technology, Science Policy Task Force, July 10, 1985, p. 1.

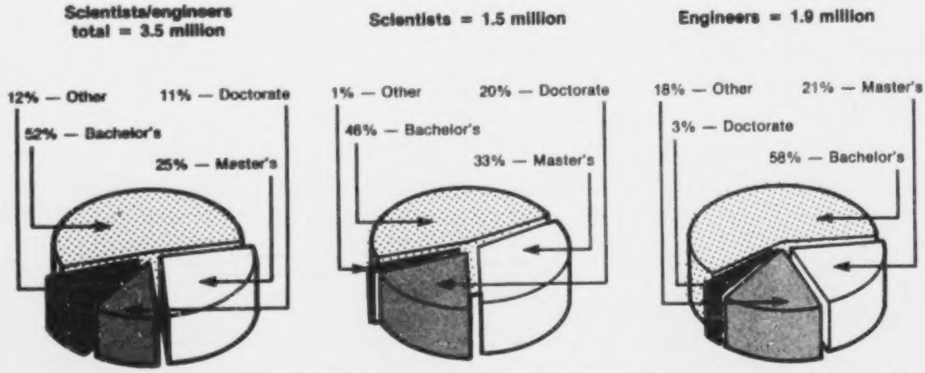
[7] *Science and Technology Resources*, NSF 85-305 (Washington, DC: National Science Foundation, January 1985), pp. 53-65.

Figure 1-1.—Population of U.S. Scientists and Engineers by Field, 1983



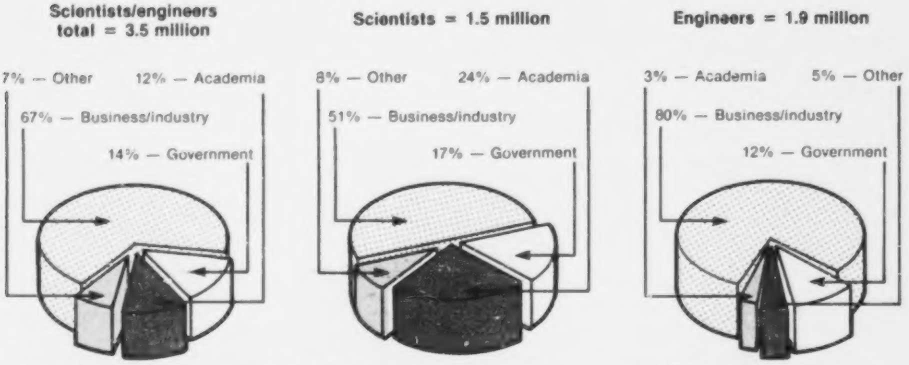
SOURCE: National Science Foundation, *Science and Technology Resources*, NSF 85-305, January 1985, pp. 53-65.

Figure 1-2.—Employed Scientists and Engineers by Highest Degree, 1983



SOURCE: National Science Foundation, *Science and Technology Resources*, NSF 85-305, January 1985, pp. 53-65.

Figure 1-3.—Employed Scientists and Engineers by Sector, 1983



SOURCE: National Science Foundation, *Science and Technology Resources*, NSF 85-305, January 1985, pp. 53-65.

The racial, sexual, and ethnic composition of the scientific and engineering work force is also quite complex and varied. Blacks, who constitute 10.4 percent of the national labor force, only constitute 2.6 percent of the scientists and engineers, ranging from a high of 6 percent of the social scientists to a low of 0.6 percent of the environmental scientists. Hispanics, who are 5.5 percent of the total labor force, represent only 2.3 percent of the Nation's scientists and engineers. At the other extreme, Asians, who constitute 1.6 percent of the national labor force, make up 4.5 percent of the science and engineering work force.

Women make up 43.5 percent of the civilian labor force, but only 13.1 percent of the scientists and engineers. They are especially well represented in the mathematical sciences (45.8 percent) and psychology (40.9 percent), and especially poorly represented in engineering (3.5 percent) and physical science (11.7).[8] There is concern that the low participation rates of women, blacks, and Hispanics in science and engineering reflect not only tastes and preferences but also social and cultural barriers to equal opportunity in those fields.

DEMOGRAPHIC TRENDS AND THE POSSIBILITY OF FUTURE SHORTAGES

The U.S. population grew from 152 to 234.5 million between 1950 and 1983, and is projected to increase to 283 million by the year 2010.[9] The rate of growth has slowed dramatically, from 19 percent between 1950 and 1960 to 11 percent between 1970 and 1980, and a projected 5.6 percent between 2000 and 2010. Within that overall growth, different subpopulations have experienced very different patterns of change, as can be seen from figure 1-5.[10] The school age and preschool populations (from birth to 17)

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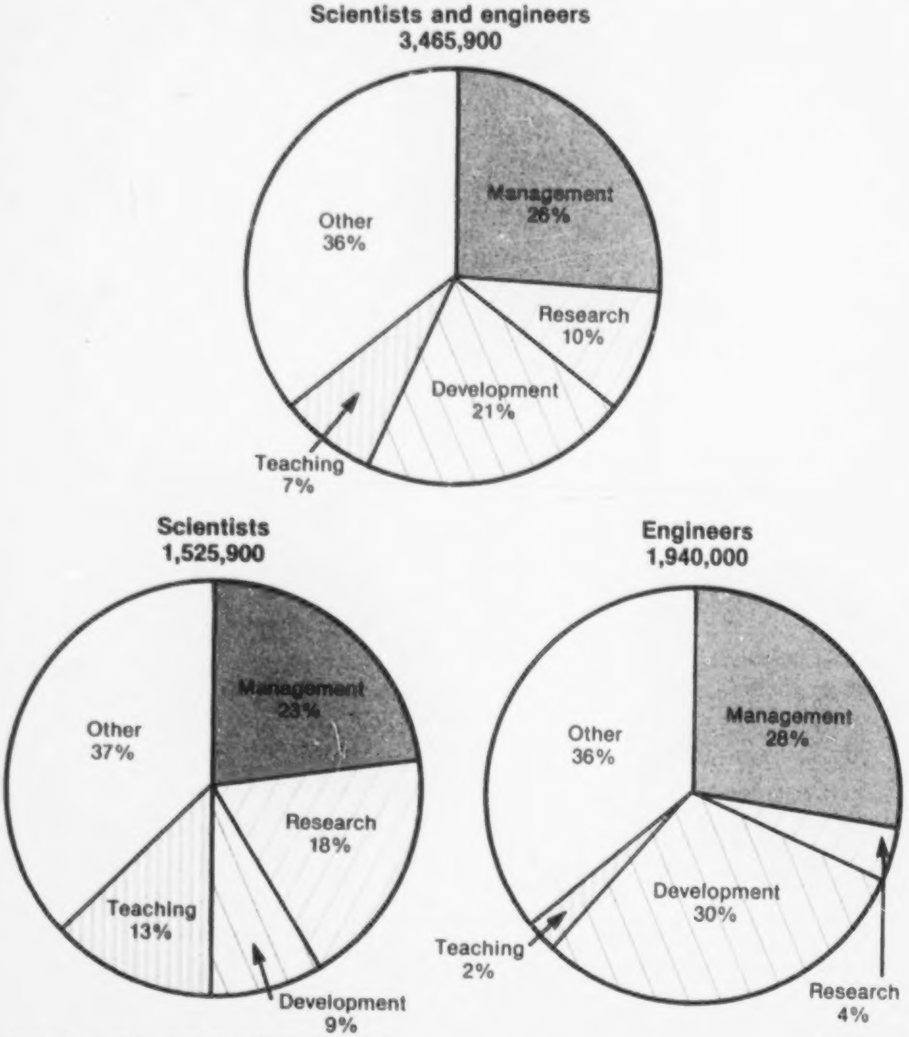
[8] *Professional Women and Minorities*, 5th ed. (Washington, DC: Scientific Manpower Commission, August 1984), p. 96.; *Statistical Abstract of the United States, 1985* (Washington, DC: U.S. Department of Commerce, Bureau of the Census, 1985), pp. 391, 392.

[9] *Projections of the Population of the United States, by Age, Sex and Race: 1983 to 2080*, Series P-25, No. 952 (Washington, DC: U.S. Department of Commerce, Bureau of the Census, May 1984), table E, p. 7. See also, *Statistical Abstract of the United States, 1985*, op. cit., table 27, p. 26.

[10] *Projections of the Population*, op. cit., table E, p. 7.

Figure 1-4.—Employed Scientists[a] and Engineers by Primary Work Activity, 1983



Scientists and engineers 3,465,900

Scientists 1,525,900

Engineers 1,940,000

[a] Includes social scientists and psychologists.

SOURCE: National Science Foundation, *Science and Technology Resources*, NSF 85-305, January 1985, pp. 53-65.

grew rapidly between 1950 and 1970, and have essentially leveled off since. The college and university age population (18 to 34) underwent significant expansion between 1960 and 1980, will contract in size again between 1990 and 2000, and then expand somewhat between 2000 and 2010. The senior working age population, 35 to 64 years old, will expand dramatically in size between 1980 and 2010, as will the total number of elderly people, aged 65 and over.

Figures 1-6 and 1-7[11] display these population changes in somewhat greater detail. They show the percentage of the population in each age group in every fifth year from 1950 to 2000 and the year 2010. By following the bars

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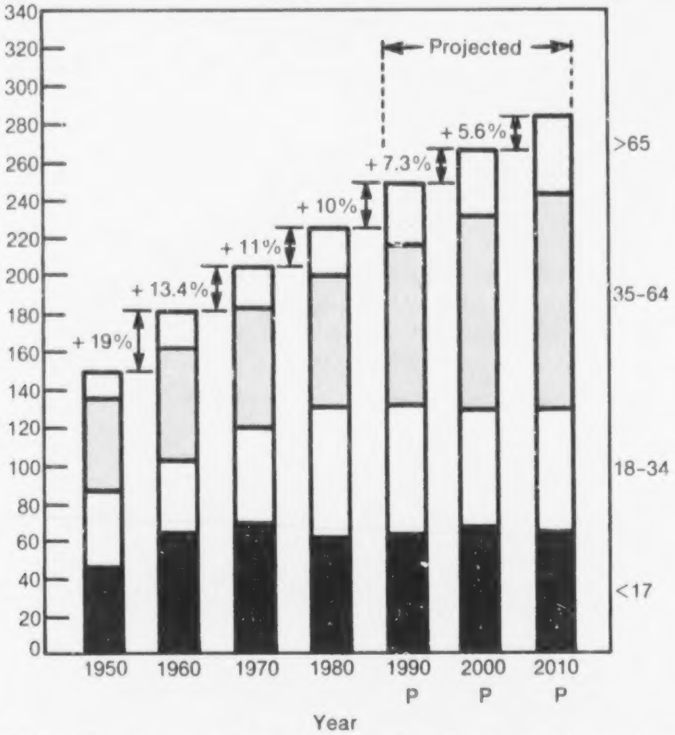
[11] Ibid., table F, p. 8.

Figure 1-5.—U.S. Population by Major Age Group, 1950-2010



SOURCE: *Projections of the Population of the United States, by Age, Sex and Race: 1983 to 2080*, series P-25, No. 952 (Washington, DC: U.S. Department of Commerce, Bureau of the Census, May 1984), table E, p. 7.

from left to right on each graph one can trace the effects of the "baby boom" of the post World War II era on each population group. The successive peaks in population—1960-70 for the 5 to 13 year olds; 1975-85 for the 18 to 24 year olds; 1990-2000 for the 35 to 44 year olds—are exhibited, as are the subsequent dramatic declines in the percentage shares of the different groups following the "baby boom," and the rather modest "baby boom echo" of the early 1980s.

The groups of concern in this essay are the 18 to 24 year olds and the 25 to 34 year olds, the two subpopulations that contribute in greatest numbers to undergraduate and graduate enrollments. Therefore, it is worth looking at the demographic trends for these two subgroups in somewhat greater depth. Figure 1-8[12] presents the population trends for 18 to 24 and 25 to 34 year olds over the 1950-2010 time period. The figure shows the dramatic increase in the former group between 1955 and 1980, doubling from 15 to 30 million in that period. It shows as well the 23-percent decline projected for the 1980-95 time period, followed by an 18-percent increase between 1995 and 2010. For the 25 to 34 year old group, there is a doubling in the 1965-90 time frame followed by a decline of 16 percent between 1990 and 2000.

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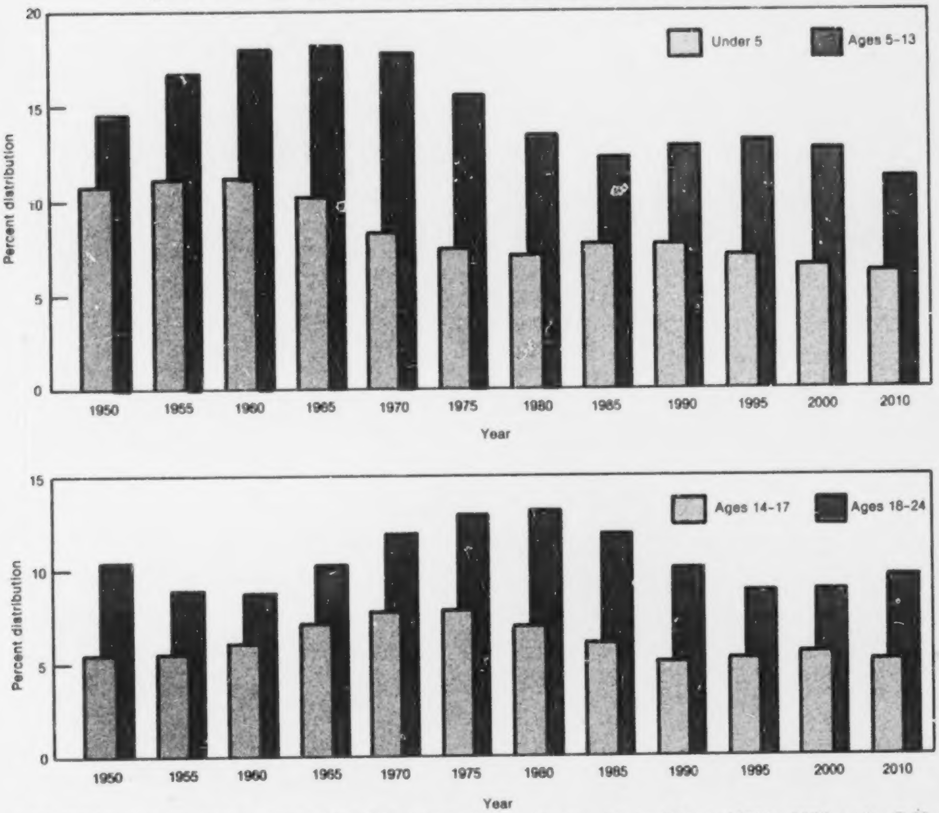
[12] Ibid., table E, p. 7.

Figure 1-6.—Population Distribution by Age, 1950-2010



SOURCE: *Projections of the Population of the United States, by Age, Sex and Race: 1983 to 2080*, series P-25, No. 952 (Washington, DC: U.S. Department of Commerce, Bureau of the Census, May 1984), table F, p. 8.

Each year about 300,000 college seniors, or 30 percent of the graduating class, receive their bachelor's degree in a science or engineering field. This overall level has remained nearly constant for close to a decade, but there have been dramatic fluctuations among fields (see examples on p. 21).[13] Science and engineering masters degrees have remained relatively constant in the 53,500 to 56,500 per year range since 1972, with social science and engineering each accounting for more than 25 percent of the total. The number of science and engineering doctorates peaked at 19,000 in 1972 and has fluctuated between 17,000 and 18,000 a year since 1976.[14] (See figures 1-9, 1-10 and 1-11.[15])

The relatively constant rate of production of scientists and engineers over the past decade could be significantly affected by the projected decline in the college age population in the near future. Labor market specialists esti-

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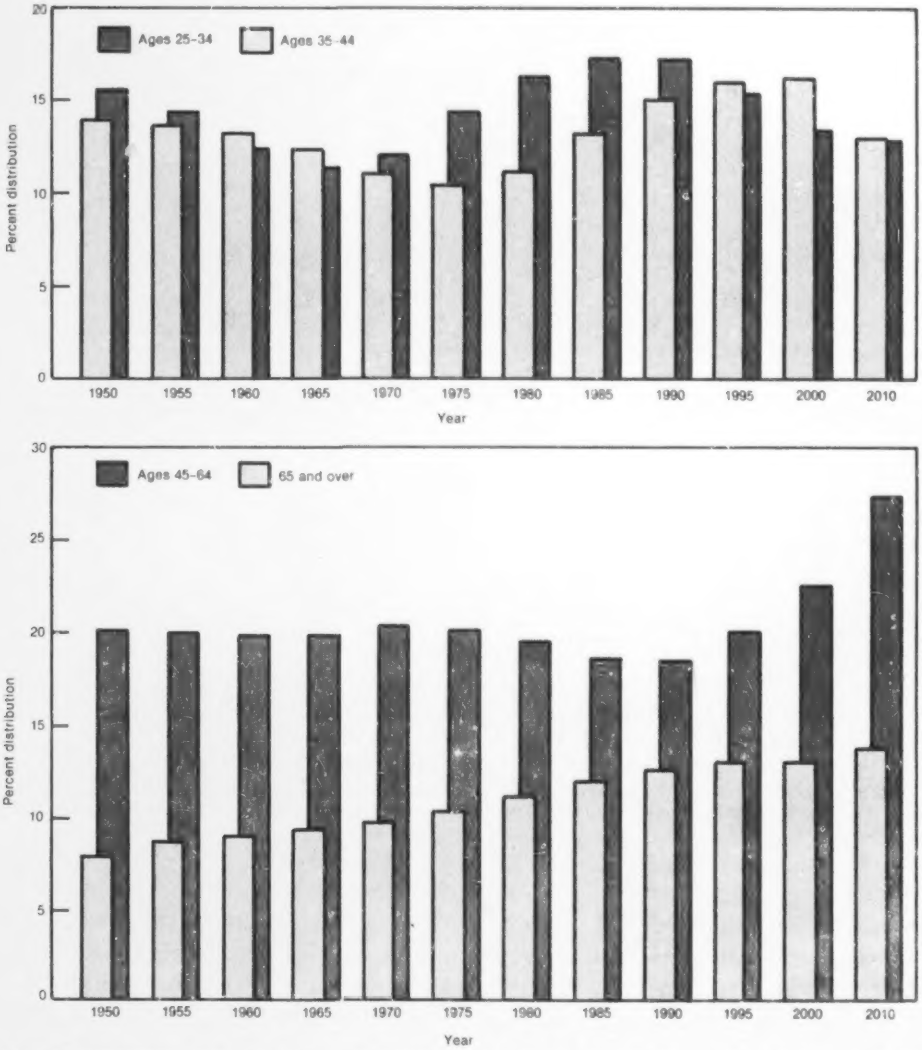
[13] *Science and Technology Resources*, op. cit., pp. 73-74.

[14] *Science and Engineering Personnel: A National Overview*, NSF 85-302 (Washington, DC: National Science Foundation, 1985), pp. 154-156.

[15] *National Patterns of Science and Technology Resources, 1984*, NSF 84-311 (Washington, DC: National Science Foundation, 1984), pp. 29-30.

Figure 1-7.—Population Distribution by Age, 1950-2010



SOURCE: *Projections of the Population of the United States, by Age, Sex and Race: 1983 to 2080*, series P-25, No. 952 (Washington, DC: U.S. Department of Commerce, Bureau of the Census, May 1984), table F, p. 8.

mate that the decrease in 18 to 24 year olds discussed above could lead to a drop in college enrollments of 12 to 16 percent between now and 1995.[16]

In addition to these changes in the overall numbers, there will be qualitative changes in the student mix that could affect science and engineering. The percentage of minorities in the 18 to 24 year old cohort will increase from 20 to about 27 percent by 1998,[17] so the increasing participation of blacks, Hispanics, Asian Americans, and other minorities in higher education that took place in the 1970s (minority enrollments increased 86 percent from 1972 to 1982) can be expected to continue. (The decline in the

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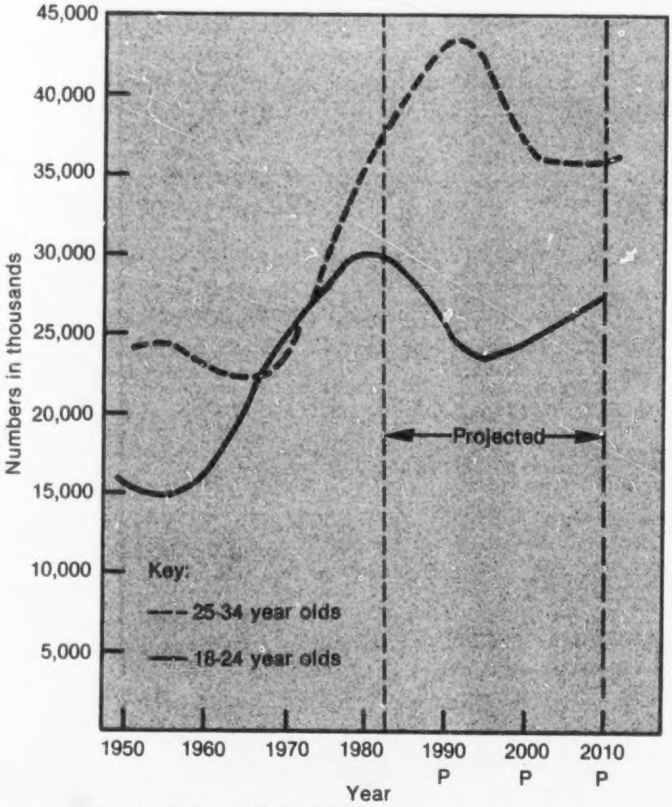
[16] *Research Excellence Through the Year 2000* (Washington, DC: National Research Council, Commission of Human Resources, 1979), pp. 12-15; William Bowen, *Report of the President* (Princeton, NJ: Princeton University, April 1981), pp. 11-15.

[17] *Statistical Abstract*, 1985, op. cit., pp. 26-34.

Figure 1-8.—18-24 Year Olds and 25-34 Year Olds in the U.S. Population, 1950-2010



NOTE: Figures for 1983 to 2010 are projected.

SOURCE: *Projections of the Population of the United States, by Age, Sex and Race: 1983 to 2080*, series P-25, No. 952 (Washington, DC: U.S. Department of Commerce, Bureau of the Census, May 1984), table E, p. 7.

rate of college enrollment among black high school graduates since 1978 casts some doubt on this prediction as it relates to the black community.) These groups, with the exception of Asian Americans, have historically participated less actively in science and engineering education than the majority population. The numbers of women, part-time students and students in 2-year institutions all increased by about 70 percent in the decade from 1972 to 1982, approximately twice as rapidly as the overall increase in higher education enrollments.[18] These groups also participate in science and engineering education at lower rates than their white male full-time counterparts at 4-year colleges and universities.

Assuming that science and engineering degrees continue to represent no more than 29 to 30 percent of the total baccalaureates awarded in any year, as they have since 1972, the decrease in the 18 to 24 year old population could lead to a decline in the number of bachelor's level scientists and engineers being produced by the Nation's higher education system of a cor-

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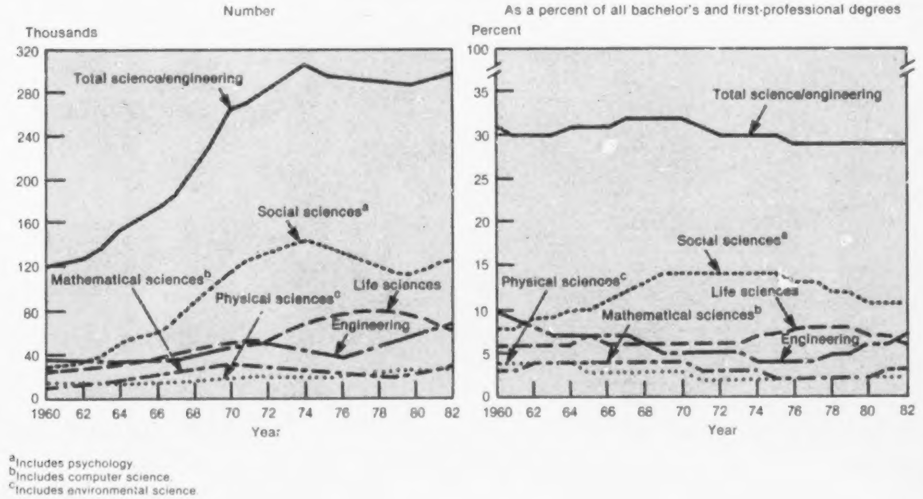
[18] *Digest of Education Statistics, 1983-1984* (Washington, DC: National Center for Education Statistics, 1984), p. 98.

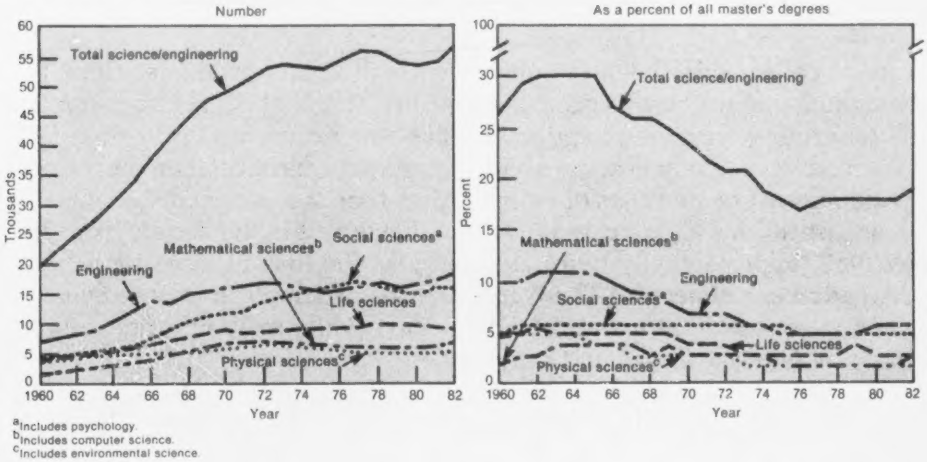
Figure 1-9.—Science/Engineering Bachelor's and First-Professional Degrees Awarded by Field



[a] Includes psychology.
[b] Includes computer science.
[c] Includes environmental science.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources*, NSF 84-311, 1984, pp. 29 and 30.

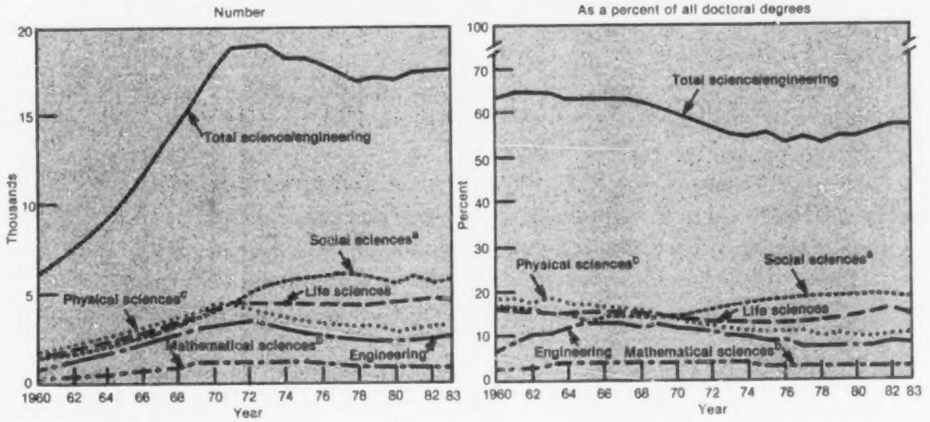
Figure 1-10.—Science/Engineering Master's Degrees by Field



[a] Includes psychology.
[b] Includes computer science.
[c] Includes environmental science.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources*, NSF 84-311, 1984, pp. 29 and 30.

Figure 1-11.—Science/Engineering Doctorates Awarded by Field



[a]Includes psychology.
[b]Includes computer science.
[c]Includes environmental science.

[a]Includes psychology.
[b]Includes computer science.
[c]Includes environmental science.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources*, NSF 84-311, 1984, pp. 29 and 30.

responding 15 percent by 1995. Similarly, the decline in 25 to 34 year olds projected for the 1990-2000 time frame could lead to a possible decrease in the number of science and engineering doctorates produced in that time period. (The master's degree has considerably less meaning in science and engineering than it does in other fields, such as business, social work, and education, so it will not be discussed at any length in this technical memorandum.)

To investigate the likelihood of this possible decline taking place, and its possible consequences for the Nation's scientific and technical enterprise, OTA examined the historical record on the relationship between science and engineering degrees and demographic trends and on the labor market for science and engineering baccalaureates and Ph.D.s in industry and academia. OTA also reviewed recent projections of supply and demand for scientists and engineers, consulted extensively with scientific and engineering labor market specialists and carried out a number of independent studies and simulations on its own. OTA's findings from its investigation of science and engineering personnel issues are presented below. Findings 1 to 3 deal with population trends and the education and employment of science and engineering baccalaureates and Ph.D.s. Findings 4 to 6 deal with projections of supply and demand, and the functioning of the labor market for technical personnel. Findings 7 to 10 examine the barriers to equality of opportunity in science and engineering careers experienced by women and some racial and ethnic minorities, and the special problems of foreign nationals in science and engineering education and employment.

FINDINGS

Finding 1

Population trends, although important, do not have as great an impact on the supply of scientists and engineers as do career choices and market forces.

Less than 7 percent of the members of a given age cohort currently receive a bachelor's degree in a science or engineering field. Less than 0.5 percent achieve the doctorate in one of those fields.[19] These very small percentages imply that changes in the overall size of the age cohort should have far less of an effect on the number of scientists and engineers produced in a given year than variations in the rate at which students choose to enter those fields. A slight increase in the rate of selection of science and engineering careers among college age students could more than compensate for the decline in 18 to 24 year olds projected for the 1982-95 time frame. For example, if the rate of attainment of science and engineering bachelor's degrees were to increase from the 1982 level of 6.8 percent of the 22 year old population to the 1973 level of 8.2 percent,[20] that would cause a rise in the number of degrees awarded in these fields of 20 percent.

Less than two-thirds of those receiving science and engineering baccalaureates in recent years have actually become part of the science and engineering work force. The National Science Foundation (NSF) conducted a survey of science and engineering bachelor's degree holders in 1982 to determine the experience of the classes of 1980 and 1981 in making the transition from school to work. It found that only 43 percent of the science and engineering baccalaureates from those 2 years were employed in a science or engineering field a year or two later.[21] An additional 21 percent were enrolled in graduate school full time, although not necessarily in science or engineering. Twenty-eight percent were employed outside of science and engineering, 5 percent were unemployed and seeking employment, and 4 percent were outside the labor force. Thus, less than two-thirds of the 1980-81 science and engineering baccalaureates were actually in the science and engineering work force a year after graduation. This percentage varied from a low of 43 percent in the social sciences to a high of over 80 percent in engineering, computer science, and the physical sciences, with mathematics and the life sciences directly in the middle, at 70 and 67 percent, respectively.

There is, moreover, no national market for scientists and engineers as a group. Rather, there are individual markets for graduates trained in particular disciplines, and these markets and disciplines experience very different conditions at the same time. For example, there is currently alleged to be an 8 percent vacancy rate in engineering faculty positions at a time when new Ph.D.s in sociology, mathematics, and other fields are having trouble finding university employment.[22] NSF projects that the demand for electrical and aeronautical engineers and for computer specialists could exceed the supply of graduates in those fields by as much as 30 percent over the 1981-87 time frame, while at the same time there will be significantly fewer openings for biologists, chemists, geologists, physicists, mathematicians, chemical, civil, and mechanical engineers than there will be trained degree holders.[23] Nearly 28 percent of the science baccalaureate holders in 1981 obtained employment outside of science and engineering in the same year that 40 percent of the firms responding to an NSF survey reported shortages of engineers.[24] **Thus, it is individual disciplines, especially those linked with high growth or defense-oriented industries, which could experience problems; not "science and engineering" as a whole.**

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[19] *Science and Technology Resources,* op. cit., pp. 74 and 78; *Projections of the Population,* op. cit., table 5, p. 38.

[20] *Science and Engineering Degrees: 1950-1980,* NSF 82-307 (Washington, DC: National Science Foundation, 1982), p. 60.

[21] *National Patterns of Science & Technology Resources, 1984,* op. cit., p. 24.

This finding is encouraging, because individual disciplines have shown great ability to grow and shrink as market conditions require. The number of engineering baccalaureates, for example, more than doubled between 1976 and 1984.[25] The number of bachelor's degrees in computer and informational science tripled between 1977 and 1982. At the same time those in education, foreign languages, anthropology, history, and sociology all fell by 30 percent or more.[26] Thus, **college students appear to be highly responsive to market signals, and appear to shift their career choices dramatically toward fields that promise greater occupational rewards.**[27] Engineering and computer science have been highly marketable majors over the past 5 to 10 years, as measured by the numbers of job offers and level of starting salaries for bachelor's degrees in those fields. Foreign languages, history, sociology, and anthropology, by contrast, are all fields that have experienced relatively weak job markets in the past decade.

Finding 2

Levels of graduate enrollment and Ph.D. production in science and engineering appear to be largely independent of general demographic trends.

Between 1960 and 1970 the number of full-time graduate science and engineering students enrolled in U.S. institutions of higher education increased 150 percent, from 78,000 to 188,000.[28] The number of science and engineering Ph.D.s awarded increased 183 percent, from 6,300 in 1960 to 17,700 in 1970.[29] At the same time the population of 22 to 34 year olds—the group that supplies the majority of graduate students—increased only 18 percent.[30]

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[22] Michael S. McPherson, "The State of Academic Labor Markets," November 1984, draft, p. 5. To be published in B.L.R. Smith (ed.), *The State of Graduate Education* (Washington, DC: The Brookings Institution, 1985).

[23] *Projected Response of the Science, Engineering and Technical Labor Market to Defense and Nondefense Needs: 1982-1987,* NSF 84-204 (Washington, DC: National Science Foundation, 1984), p. 43.

[24] *National Patterns of Science and Technology Resources, 1984,* op. cit., p. 24.

[25] *Engineering Education and Practice in the United States* (Washington, DC: National Research Council, 1985), p. 57; and *Manpower Comments* (Washington, DC: Scientific Manpower Commission, January-February 1985), p. 34.

[26] McPherson, op. cit., table 1.

[27] Sue E. Berryman, in an exhaustive study of "The Adjustments of Youth and Educational Institutions to Technology Generated Changes in Skill Requirements," Research Report Series, RR-85-08 (Washington, DC: National Commission for Employment Policy, May 1985), finds that "young people generally are responsive to changing market signals; they alter their fields of study, increase or decrease the amount of time they spend on formal education, and are very mobile both geographically and occupationally" (p. i.).

[28] Fallows, op. cit., p. 10.

Between 1970 and 1982 the situation changed dramatically. Graduate enrollments in science and engineering increased by only 36 percent; annual doctorates awarded decreased by 1 percent, but the graduate school age population increased by more than 50 percent. Thus, **there is no evidence of a direct relationship between graduate enrollments and Ph.D.s in science and engineering, and changes in the graduate school age population.**

The dramatic expansion in Ph.D. production and graduate enrollment in science and engineering that occurred in the 1960s was apparently related to four simultaneous developments. First, Federal support for graduate education in general, and science and engineering education in particular, grew enormously in that decade. The number of Federal graduate fellowships and traineeships increased from 8,000, of which 5,000 were in science and engineering in 1960, to 52,000, of which 36,000 were in science and engineering in 1969. The number of research assistantships in science and engineering increased from about 5,000 in 1954 to over 15,000 in 1969.[31] At the same time Federal support was expanding, State and institutional aid to graduate education, especially in the form of teaching assistantships, also increased dramatically, to more than 50,000 graduate students in 1969.[32]

In addition to increased Federal and State support for graduate education there was a third factor, a surging demand for Ph.D.s, especially in academia, in that era. The number of junior faculty openings exceeded the number of doctorates awarded by 50 percent (260,000 openings; 170,000 doctorates) between 1961 and 1970.[33] (See figure 1-12.[34]) In addition, the Federal research and development (R&D) budget quadrupled in that decade, creating a sizable demand for doctoral scientists and engineers as researchers.

Finally, popular opposition to the Vietnam War led many male college graduates to enroll in graduate school to avoid the draft.

In the 1970s, when the growth in academic demand and Federal R&D funding slowed, the military draft ended, and the level of Federal support for graduate fellowships and traineeships decreased dramatically, Ph.D. production began to fall. It fell most rapidly in those fields where Federal fellowships and traineeships and R&D funds declined most severely (i.e., engineering, mathematical sciences, and physical sciences).

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[29] Ibid., p. 11.

[30] *Statistical Abstract of the United States, 1979* (Washington, DC: U.S. Department of Commerce, Bureau of the Census, 1979), pp. 160 and 29.

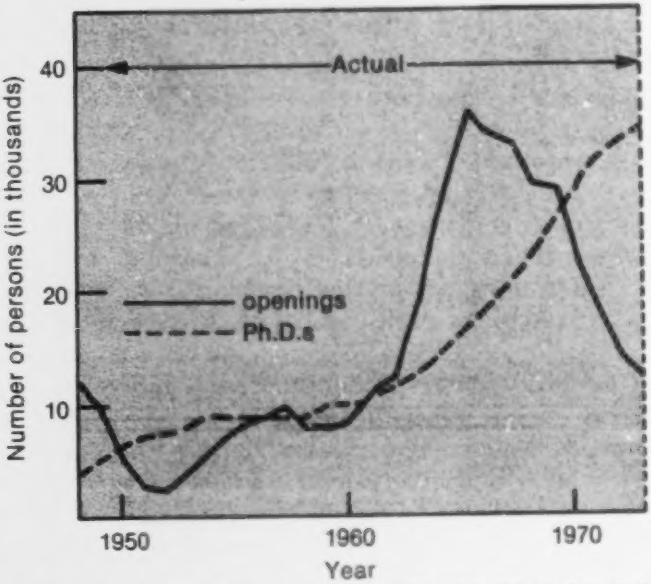
[31] Federal Inter-agency Committee on Education, "Report on Federal Predoctoral Student Support," April 1970, tables 1-10. R.G. Snyder, "The Effectiveness of Federal Graduate Education Policy and Programs in Promoting an Adequate Supply of Scientific Personnel," contractor report prepared for the Office of Technology Assessment, June 1985, p. 14.

[32] Snyder, op. cit., p. 18.

[33] Allan Cartter, *Ph.D.s and the Academic Labor Market* (New York: McGraw-Hill, 1976), p. 143.

[34] Ibid., p. 129.

Figure 1-12.—Comparison of Junior Faculty Openings With Earned Doctorates Awarded (actual 1948-73)



SOURCE: Allan Cartter, *PhD's and the Academic Labor Market* (New York: McGraw-Hill, 1976), p. 129.

Finding 3

A combination of faculty and student demographics will lead to a weak academic market for new Ph.D.s over the next decade, followed by an upsurge in academic hiring between 1995 and 2010.

The projected decline in student enrollments discussed above, coupled with a low retirement rate among current faculty (most of whom were hired in the late 1960s and will not retire until the late 1990s), will lead to a very weak academic market for new Ph.D.s in the next decade. This decline was predicted by a number of scholars in the 1970s, and has been confirmed by analyses carried out this year by OTA and the National Academy of Sciences.[35] According to the OTA analysis, the total academic demand for new science and engineering doctoral degree recipients should average about 3,000 to 6,000 per year from 1983 to 1998. This is less than one-third the annual number of new Ph.D.s projected for the period under the assumption that such degrees will remain constant at about 18,000 per year, and 40 to 80 percent of the rate of hiring for new science and engineering Ph.D.s in academia that existed in the 1978-83 time frame (about 8,000 new hires per year). After 1998 the demand for new science and engineering faculty and research personnel in academia should increase substantially, due to increases in both enrollments and retirements. According to OTA analysis, the academic demand for new science and engineering Ph.D.s could be roughly the same from 1998 to 2013 as the level of hiring that took place during the 1970s. The pattern of decline followed by increase will be experienced separately over the next quarter century by each of the major science and engineering fields. (See chapter 3 for the analysis that supports these projections.)

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[35] National Research Council, *Forecasting Demand for University Scientists and Engineers: Proceedings of a Workshop* (Washington, DC: National Academy of Sciences, 1985), p. 1.

The trends discussed above pose two significant policy-related questions. First, should steps be taken now to increase the demand for new Ph.D.s during the decline decade of 1988 to 1998, in order to smooth out the hiring pattern over the next quarter century and prevent potential graduate students from becoming discouraged from pursuing a research career due to the weak near term academic market? The National Institutes of Health (NIH) system for training and supporting biomedical research personnel appears to be an example of a self-conscious and explicit Federal personnel policy in an important scientific field that could be emulated elsewhere. Consistent Federal support for biomedical research in terms of funding of research and training has produced both a substantial supply and demand for investigators. This has created a steady-state system in which there have been no major shortages of biomedical personnel, although some analysts believe there to be a surplus of biomedical Ph.D.s today. However, it is a large system which would be difficult to reduce in significant ways without major dislocations.

Unlike most other fields of science, there is an institutional feedback mechanism between NIH and the Institute of Medicine (IOM) that ensures a periodic assessment of the status of biomedical research personnel. This represents, to some extent, informed decisionmaking in the implementation of research training programs. The current number of trainees is quite close to the number recommended by the IOM committee. Allocation of Federal support to either predoctoral training or postdoctoral training is a method of fine tuning that can potentially be used to control the supply of biomedical investigators. (See appendix A for an in-depth analysis of Federal education and manpower policies with respect to biomedical personnel.)

Second, in the expansion period of 1998-2013, will the combined requirements of industry and academia for science and engineering Ph.D.s exceed the annual supply? The number of science and engineering Ph.D.s employed in industry has grown at the rate of 8 percent per year over the past decade.[36] If this rate of growth continues, the industrial demand for new science and engineering Ph.D.s could exceed 10,000 per year by the first decade of the 21st century. The combined academic and industrial demand for new science and engineering Ph.D.s could then exceed the level of Ph.D. production for that period.

Finding 4

Long-term projections of supply and demand for scientists and engineers in the economy as a whole are inherently unreliable.

Apart from academia, where known demographic trends exert considerable influence on the demand for new faculty, long-term projections of demand for scientists and engineers in the overall economy are fraught with uncertainty and are relatively unreliable. Such projections depend on assumptions about the future behavior of variables such as GNP growth, defense spending, technological change, and Federal and industrial R&D expenditures, which themselves are not known with any degree of certainty. Unexpected changes in any of the input variables can cause major inaccuracies in the projections. For example, the Bureau of Labor Statistics (BLS) projects the requirements for different occupations 10 and 15 years into the future, and provides an "early warning" to high school and college students through its annual *Occupational Outlook Handbooks,* which are distributed to guidance counselors. Labor economist Lee Hansen took the projections made by BLS in 1960 and 1965 for the number of engineers that would be required in different disciplines in 1975 and 1980, and compared them with the actual numbers that were employed in those years.[37] He found that BLS overprojected the requirements for aeronautical, civil, and mechanical engineers by 20 to 55 percent. The errors were caused by the understandable failure of the BLS to anticipate the cutback in Federal R&D expenditures in the early 1970s and the recession in the mid-1970s. However, the BLS overprojections would have lead analysts to overestimate the growth component of the annual demand for engineers between the early 1960s and the late 1970s by 120 to 600 percent.

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[36] *Characteristics of Doctoral Scientists and Engineers in the United States,* NSF 85-303 (Washington, DC: National Science Foundation, 1985), table 2, pp. viii and ix.

Projections of supply are equally problematic. It is extremely difficult to predict the career choices of undergraduates or graduate students, or their responsiveness to changes in demand in technical fields. In the absence of such a predictive capability, analysts in the past tended to assume the continuation of existing trends, an assumption which can lead to gross inaccuracies. For example, in 1967 NSF, extrapolating from existing trends, projected there would be 30,500 doctorates awarded in science and engineering in 1975.[38] The actual number turned out to be 17,784. A large number of scientific "manpower" analysts in the late 1960s and early 1970s made similar errors for the same reasons. In the absence of a causal model that can accurately predict changes in career selection patterns, any supply projections are no better than educated guesses.

Given the problems of projecting supply and demand, predictions of shortages or surpluses based on such projections are not likely to be very reliable. This is not, however, a serious problem, for reasons that are discussed in the next two findings.

Finding 5

Labor markets adjust to supply-demand gaps.

Most projections of shortages assume tacitly that demand and supply are independent, so that there can be no adjustment to projected supply-demand gaps. This assumption makes sense, however, only under certain *very restrictive* conditions:

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[37] *Labor Market Conditions for Engineers: Is There a Shortage?* (Washington, DC: National Research Council, 1984), pp. 89-92.

[38] *The Prospective Manpower Situation for Science and Engineering Staff in Universities and Colleges: 1965-1975* (Washington, DC: National Science Foundation, 1967), p. 16.

1. that demand for the final product is relatively unaffected by labor costs;
2. that supply is not appreciably affected by wage changes; and
3. that the skill shortages are unique, in that workers possessing them cannot be replaced by workers from other occupations or by new technology.

If *any* of these conditions are violated, then a projected supply-demand gap can be closed by market adjustment. These conditions are *very* restrictive: They apply to only a few limited sectors, such as some parts of the defense industry and certain startup firms that require highly specialized personnel.

The essence of a labor market is that it adjusts. A projected gap between supply and demand usually does not indicate an impending shortage, but rather that some sort of adjustment must take place. The adjustment can be made either by employees or employers, or both. On the employees' side, an increasing number of entry level professionals can become trained in the shortage area, or experienced workers from neighboring specialties can move into the shortage occupation. On the employers' side, they can offer higher salaries; increase their search and recruiting efforts; rearrange jobs to utilize the available skills, education, and experience more efficiently; or make larger investments in internal training and retraining of their existing work force. Cutting back output, or the level of research and development, due to personnel shortages is probably the response of last resort.

Labor market and scientific "manpower" specialists consulted by OTA agreed that it is more important to try to understand the *process* of adjustment of the technical labor market to supply-demand imbalances than it is to make long-term projections. There can be significant problems with labor market adjustments that need to be understood by policymakers. For example, although students shift their career interests to follow signals from the marketplace, as we have seen above, this response is not a short-term remedy to a supply-demand gap because it takes 4 years to train a new engineer and 6 years (from the baccalaureate) to train a Ph.D. scientist. In a fast-moving market, the needs of employers may change by the time entering students graduate. This lag effect is especially powerful for occupations that are subject to sudden unanticipated surges in demand, as in the semiconductor and computer industries in recent years. In addition, universities may not be able to provide sufficient resources to meet new demands on their curricula, as has recently been the case in engineering. Both universities and students may misjudge the direction of the marketplace, leading to further misallocation of resources.

Occupational mobility from related fields is the short-term response to a shortage. The primary concern about occupational mobility from the employer's point of view is that it may lower the quality of work or require expensive retraining. From a societal point of view, however, occupational mobility appears to have served the Nation well in meeting its needs for technical personnel. The Manhattan project in World War II, the Apollo program in the 1960s, the environmental and energy programs of the 1970s, and the rapid buildup of the semiconductor and computer industries all relied successfully on the importation of scientific and technical talent from related fields. Many analysts consider the mobility and adaptability of the Nation's scientific and engineering work force to be one of its greatest strengths.

Employer adjustments, such as extensive searches and retraining of personnel from related fields, involve considerable costs. For example, one analyst estimates that the cost of recruiting a new engineer can run as high as 1 year's salary. Rearrangement of jobs within the firm can interfere with the distribution of incentives via rank and promotion. Despite these costs, several of the more mature computer companies, such as Data General Corp. and Digital Equipment Corp., have adopted systematic training approaches. Faced with a continuing series of shortages, they have shifted from their traditional "buy" to a "make" strategy for obtaining skilled personnel. This helps lower the turnover rate and increases the supply of experienced engineers, who are in short supply.

Finding 6

The Federal role in alleviating potential shortages of technical personnel appears limited to assistance for education and retraining.

OTA carried out an analysis of the labor market in electrical engineering, a profession that has experienced reported shortages in the recent past, is heavily involved in areas of rapid technological change, and faces demand from both the military and civilian sectors of the economy. OTA found that the supply of entry level electrical engineers is likely to stay nearly in balance with demand for the foreseeable future, as occupational mobility makes up the difference between the number of entry level engineers needed and the number of college graduates actually holding electrical engineering degrees. However, some educational institutions report that they do not have sufficient resources to train all the potential electrical engineering students who are interested.

The spot shortages of experienced engineers with specific areas of expertise reported in surveys of electronics and computer firms in the recent past will undoubtedly continue. When a particular technology gets "hot," engineers who know the field and can handle the overall design of a project are in great demand. If the technology is new or has not been used extensively in the past, the supply of engineers who combine these attributes can fall short of demand. Unfortunately, these shortages are not of a type amenable to government intervention. The government might be able to help by promoting the retraining of experienced engineers into new startup fields. Mission-agency sponsored R&D programs could conceivably serve that retraining function. The Federal energy and environment programs of the 1970s, for example, helped retrain significant numbers of engineers to become specialists in those two fields.

As to the effects of increased military spending on the market for electrical engineers, OTA did not find this to be a significant cause for concern.

The most definitive short-term projections by NSF[39] indicate that a shift from low to high defense spending would only increase the demand for electrical engineers by 4 to 5 percent, turning a slight shortage into a slightly larger one. In a survey of firms that employ electrical engineers in the Boston area, OTA found that shortages are not perceived to vary much by the level of military procurements. Many respondents felt that the two climates of military and civilian work are so very different that there is low mobility between the two "sectors."

Finding 7

Near-term demographic trends enhance the importance of promoting equality of access to scientific and engineering careers for women and disadvantaged minorities.

The Science Policy Task Force recommended that the study of demographics and the science and engineering work force also examine issues related to the participation of women and minorities in science and engineering careers, with special attention paid to the identification of barriers to participation and means of lowering those barriers.[40] OTA finds that the changing college student demographics of the coming decade have several important implications for national policy to promote equality of opportunity in science and engineering. Since the number of college graduates will decline substantially, it becomes especially important to utilize all potential human resources to the fullest extent possible. This means that increasing attention should be paid to those groups with historically low participation rates in science and engineering, such as women and some minorities. The increasing fraction of college students that will be drawn from the black and Hispanic populations, which have historically participated in science and engineering education and employment at far lower rates than the white population, imply that programs aimed at increasing the participation of these two minority groups could be an especially important source of new talent.

Finding 8

Gender-stereotyped career expectations and differential treatment of women scientists in the work force are the two major factors discouraging women from entering science and engineering.

The literature on the factors that discourage women from participating in science and engineering careers is extensive and well developed. Two factors stand out as crucial. These are gender-stereotyped career expectations among younger women entering the science and engineering talent pool, and differential treatment of women scientists and engineers in the work force.

Gender-stereotyped career expectations are manifested most dramatically in the major field preferences of college freshmen, where 20 percent of the men, but only 3 percent of the women surveyed in 1984 listed engineering as their field of choice.[41] By contrast, only 4 percent of the men, but 21 percent of the women, listed education, nursing, or occupational and physical therapy as their preferred major. In other sciences, women were *more likely* to select a social or biological science major than men, and slightly less likely to be interested in the physical sciences. These differences are often explained as the result of women's alleged lower preference for or lesser ability in quantitative fields. But the fact that freshmen women select mathematics, accounting, and business at the same rate as men casts doubt on that explanation. Rather, it appears that fields that are heavily associated with "men's work" tend to be avoided by women, just as fields that are stereotypically associated with women are avoided by men.

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[39] *Projected Response of the Science, Engineering and Technical Labor Market to Defense and Nondefense Needs: 1982-1987,* op. cit., p. 43.

[40] *An Agenda for a Study of Government Science Policy,* op. cit., p. 31.

A second aspect of gender-stereotyped career planning has to do with girls' expectations of how they will be able to allocate their time during adulthood between participation in the labor force and work in the home. Sue Berryman finds that "the more that girls expect continuous labor force participation during adulthood, the more their occupational goals approximate those of their male counterparts." She also finds that "since career goals seem to determine educational investments, gender differences in occupational expectations become key to understanding gender differences in high school mathematics participation,"[42] a key element in pursuing a science or engineering career. These expectations are in fact derivative of gender stereotyping in the work force as a whole. In our society women are still expected to assume the major role in housekeeping and child rearing, and to sacrifice their professional interests to those of their husband. As long as that situation exists, women will be less likely than men to select occupations like science and engineering that require major educational and labor force commitments. Berryman finds, interestingly enough, that *male single parents* "make occupational and labor force adaptations to parenting that look like the occupational and labor force plans of girls who expect dual family and work responsibilities."[43]

Women's experience in the science and engineering work force is decidedly different from that of men. Women's attrition rates are 50 percent higher than men's: in 1982, 25 percent of women scientists and engineers but only 16 percent of men were outside of the science and engineering work force.[44] Women's unemployment rates are significantly higher: 4.5 percent v. 1.9 percent for men. Women's salaries are significantly lower than men's in almost all fields of science, in every employment sector and at comparable levels of experience, although recent female entrants to the science and engineering work force are doing considerably better than their more senior counterparts. In academia, men are far more likely than women to hold tenure track positions, to be promoted to tenure, and to achieve full professorships. This holds true even for men and women of identical academic age (number of years since receiving the doctorate), field, and quality of graduate school attended.[45]

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[41] A.W. Astin, et al., *The American Freshman: National Norms for Fall 1984* (Los Angeles, CA: Cooperative Institutional Research Program, University of California at Los Angeles, December 1984), pp. 16-18, 32-34.

[42] Sue E. Berryman, "Minorities and Women in Mathematics and Science: Who Chooses These Fields and Why?" May 1985, typescript, p. 14.

[43] Ibid.

[44] Ibid., p. 7.

The differential treatment of women in the work force most directly violates the principal of equality of opportunity because it affects people who have established, by virtue of obtaining an advanced degree, the right to pursue a scientific or engineering career based solely on the quality of their work. It also has a significant effect on female students in the educational pipeline. A woman student in a department where no women have been hired or promoted to tenure is not likely to form a positive picture of her future employment prospects. Nor will she experience the kind of role model which the literature on equality of opportunity suggests is desirable to assist her in identifying with her future profession. Finally, the higher unemployment and attrition rates among women in science and engineering as compared to men represent a serious waste of human resources cultivated at considerable expense to the Nation and the individual.

Finding 9

Blacks, Hispanics, and American Indians are affected by a variety of socioeconomic factors that lead to poor academic performance and an inability to remain in the science and engineering educational "pipeline."

Blacks, Hispanics, and American Indians receive degrees in quantitative fields at less than half the rate of whites, due to their tendency both to participate in higher education and to select quantitative fields at substantially lower rates.[46] The quality of academic preparedness in secondary schools is cited by many experts as the greatest factor affecting these minorities' academic performance and baccalaureate attainment in college. Greater attrition levels in science and engineering among minorities correlate very highly with poor academic preparedness in high school as measured by grade averages and class rank. Problems with academic preparedness, in turn, appear to be related to socioeconomic factors such as parents' educational levels and social class.

Parents' education appears to be an especially important factor. Students whose parents have obtained college or graduate degrees are more often enrolled in quantitative majors than students who have less well-educated parents. Sue Berryman finds that "being second generation college not only increases, *but also equalizes,* the choices of quantitative majors across white, black, American Indian, Chicano, and Puerto Rican college freshmen."[47] A study carried out for the Departments of Defense and Labor in 1980 found that the strongest single predictor of reading abilities and scores on the Armed Forces Qualifications Test was the mother's educational level.[48] Youths whose mothers had completed eighth grade or less scored in the 29th percentile on the AFQTs. Those whose mothers had completed high school had an average percentile score of 54. Those whose mothers were college graduates averaged 71.

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[45] For details see *Women and Minorities in Science and Engineering* (Washington, DC: National Science Foundation, January 1984); and *Career Outcomes in a Matched Sample of Men and Women Ph.D.s* (Washington, DC: National Research Council, 1981).

[46] Berryman, op. cit., pp. 2-3.

[47] Ibid., p. 17.

[48] Betty M. Vetter, "The Emerging Demographics—Effect on National Policy in Education and on a Changing Work Force," background paper prepared for the Office of Technology Assessment, pp. 4-5.

Social class, according to Sue Berryman, "seems to be a proxy for family characteristics that affect school achievement." These characteristics include "the family's press for achievement, language models in the home, academic guidance provided by the home," work habits and activities of the family, and the "nature and quality of toys, games, and hobbies available to the child."[49] These characteristics correlate very highly with children's achievement scores. Later in life, social class correlates strongly with the level of resources a college student can bring to bear on his or her education. Financial problems in college are a factor cited by many analysts in explaining the poor persistence of minorities in the scientific and engineering educational system.

Despite the formidable socioeconomic problems responsible for the low participation rates in science and engineering among blacks, Hispanics, and American Indians, there is considerable anecdotal evidence that well-designed intervention programs can assist these groups in obtaining access to science and engineering careers. The American Association for the Advancement of Science, in an assessment of more than 100 such programs, found them to "have demonstrated that there are no inherent barriers to the successful participation of women and minorities in science or mathematics" if these groups are provided with "early, excellent, and sustained instruction in these academic areas."[50] These programs help stimulate an interest in science and engineering among talented students who might never have considered a career in one of those fields. They also provide supplementary instruction in science and mathematics to help improve the academic preparedness of those students who choose to major in a quantitative field. To date, programs for minorities have not been rigorously and systematically evaluated to determine the ingredients of success and failure. (Programs for women appear to have been more carefully studied.) Nor has any attempt been made on the national level to share the lessons learned from successful programs with less fortunate endeavors. NSF could take a leadership role in this area, but thus far it has not done so. In fact, the executive branch's response to the mandate it received from Congress in 1980 to develop a comprehensive program to promote the participation of women and minorities in science and engineering was to cut back or eliminate the few programs in existence in that era.[51]

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[49] Berryman, op. cit., p. 15.

[50] Shirley M. Malcom, *Equity and Excellence: Compatible Goals,* Publication 94-14 (Washington, DC: American Association for the Advancement of Science, December 1984), p. viii.

[51] The National Science Foundation Authorization and Science and Technology Equal Opportunities Act of 1980 (Public Law 96-516, 94 Stat. 3007) required the Director of NSF to prepare and transmit to Congress "a report proposing a comprehensive and continuing program at the Foundation to promote the full participation of minorities in science and technology" (Section 34b). The NSF response to this requirement, "Proposals of the National Science Foundation to Promote the Full Participation of Minorities and Women in Science and Engineering," Dec. 15, 1981, typescript provided by National Science Foundation, contains the following quote:

> The Foundation's authorizing legislation for fiscal year 1981 provided for several programs that addressed the participation of minorities and women in science and technology. These programs were reduced by rescissions in fiscal year 1981 and were deleted from the Foundation's budget request for fiscal year 1982 as part of the Administration's program for economic recovery.

Two reports required of the President by Section 35 of Public Law 96-516 were never transmitted to Congress.

Despite the problems cited above, women's participation in science and engineering has increased dramatically in all fields and at all levels. There appear to be no inherent reasons why these increases should not continue. For blacks and Hispanics the causes of low participation are so deeply entwined with larger social and cultural factors that the prospects for further improvements without dramatic societal intervention do not appear very bright. Already the rate of increase in participation among these groups has slowed significantly since the dramatic improvements of the mid-1970s.

Finding 10

The increasing participation of foreign nationals in U.S. Science and engineering education has raised a number of unresolved policy issues.

The number of foreign nationals enrolled in American institutions of higher education has increased by a factor of 10 in the past three decades, from 34,000, or 1.4 percent of the student population in 1954, to 338,000, or 2.7 percent of the student population, in 1984.[52] Foreign students tend to enroll proportionately more often in engineering and medical sciences than in humanities and social sciences. This has been attributed to the relatively high cost to a developing country of establishing proper training facilities for the engineering and natural science disciplines. A projected increase of 350,000 or more foreign college students over the next decade[53] could compensate to some degree for the expected decline in American 18 to 24 year olds.

Foreign nationals have assumed a large share of both enrollments and doctoral degrees in graduate departments of engineering, mathematics, and computer science (more than 40 percent of enrollments and degrees in engineering; 40 percent of enrollments and 25 percent of degrees in mathematics). There is concern that because science and engineering education is capital intensive, and many science and engineering graduate students are supported by Federal research assistantships, that the United States is subsidizing the training of non-U.S. citizens. However, it appears that many graduate engineering departments would have had to curtail their research and teaching activities substantially without foreign student enrollments. Moreover, analysts Lewis Solmon and Ruth Beddow have found, in a study of 1980-81 foreign degree recipients at the bachelor's, master's, and Ph.D. levels, that "foreign students probably pay more than their education costs, and they might be paying substantially more."[54] Some also argue that there are foreign policy and good will benefits to U.S. education of foreign citizens. The U.S. Agency for International Development recently announced that it would increase its scholarship support to Latin American students in order to counter Soviet leadership in this area; this may be seen as evidence for this point of view.

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[52] *Open Doors: 1983/84* (New York: Institute of International Education, 1984), table 1.3, p. 6.

[53] *Foreign Student Flows* (New York: Institute of International Education, 1985), pp. 78-79.

[54] Lewis C. Solmon and Ruth Beddow, "Flows, Costs and Benefits of Foreign Students in the United States: Do We Have a Problem," *Foreign Student Flows*, op. cit., pp. 121-122.

There is disagreement between various groups within the United States as to whether individuals admitted to the United States as students who complete a graduate degree here should be allowed to remain here after completion of the degree and perhaps a short period of further training. Increasing proportions of those earning doctorate degrees (56 percent in 1983) are remaining in the country after graduation.[55] Many employers, both in industry and in academic institutions, say that they cannot fill certain research and faculty positions with U.S. citizens, and available data verify this.[56] The Institute of Electrical and Electronic Engineers, on the other hand, contends that increasing numbers of foreign engineers earning degrees in this country are taking jobs at low pay in order to remain here, thus driving down salaries and reducing opportunities for U.S. engineers.[57] The limited statistical evidence that exists, however, indicates that foreign engineers are not paid less than comparably trained and experienced U.S. engineers.[58]

Many foreign nationals choose to enter the academic market after graduation, especially in engineering. A 1982 survey found that 18 percent of all full-time engineering faculty members earned their B.S. degrees from an institution outside the United States. Several authors have made reference to a "growing problem" of foreign nationals on engineering faculties. Analysts contend that the drawbacks of an increasingly foreign born faculty are the limitations in their communications skills and difficulties they may have in adjusting their teaching and research styles to the expectations of American culture.[59]

Foreign nationals are often unable to work on industry or government projects with national security or economic competitiveness implications. However, those students that obtain positions in industry after graduation can and often do become U.S. citizens and thereby cease to be "foreign nationals."

Finally, some analysts contend that a lack of data prevents the Nation from making informed policy decisions in this area. However, there is a great deal of information about foreign students available from the Institute of International Education, and several new research projects sponsored by NSF promise to fill many of the gaps. What is most lacking is a consensus over the definition of the "problem."

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[55] *Participation of Foreign Citizens in U.S. Science and Engineering* (Washington, DC: National Science Foundation, January 1985), p. v.

[56] Betty Vetter, "U.S. Education and Utilization of Foreign Scientists and Engineers," contractor report prepared for the Office of Technology Assessment, p. 16.

[57] See statement of Jack Doyle, Institute of Electrical/Electronic Engineers, in Scientific Manpower Commission, "The International Flow of Scientific Talent: Data, Policies and Issues," May 7, 1985, p. 29.

[58] Michael G. Finn, "Foreign National Scientists and Engineers in the U.S. Labor Force, 1972-1982," draft report to the National Science Foundation, March 1985.

[59] *The International Flow of Scientific and Technical Talent*, op. cit.

Chapter 2: Demographic Trends: Undergraduate and Graduate Education

THE CHANGING COMPOSITION OF THE UNDERGRADUATE POPULATION

Significant changes in the size, composition, and career interests of the undergraduate population have characterized the past quarter century of American higher education. Demographic and other trends indicate that similar changes, although not as rapid or extreme, will also mark the next 20 to 30 years. Since the baccalaureate is the entry-level degree to a scientific or engineering career, the composition of the undergraduate population can be expected to have a significant effect on the size and make-up of the science and engineering work force. This section will examine the changing demographic and career patterns of the undergraduate population and discuss the implications of the trends for the size and quality of the scientific and engineering work force.

The explosion in higher education that took place in the 1960s saw undergraduate enrollments increase by 120 percent, from 3.3 million in 1960 to 7.4 million in 1970.[1] This sizable change was caused only in part by demographics. The number of 18 to 24 year olds, who constituted about 70 percent of the college population,[2] also increased over the decade, but at a substantially lower rate of about 54 percent.[3] Close to half of the increase in enrollment in the 1960s was caused by an increase in the rate at which high school graduates chose to participate in higher education. In 1960 only 23.7 percent of the 18 to 24 year olds that graduated from high school were enrolled in college: by 1970 that ratio had increased to 32.7 percent, where it remains today.[4]

In the 1970s, undergraduate enrollments increased by 47 percent (from 7.4 million in 1970 to 10.9 million in 1983),[5] but the population of 18 to 24 year olds only increased 22 percent. Most of the new college students were adults 25 years and older who doubled their participation in higher education as a whole (including graduate school) in that period. More than 70 percent of the new over-25 group were adult women, whose enrollment in higher education more than *tripled* between 1970 and 1983.[6] The overall share of women in higher education increased from 41.2 percent in 1970 to 51.7 percent in 1983.[7] Blacks increased from 6.9 percent of the higher education population in 1970 to 10.6 percent in 1978, but then fell back to 9.6 percent in 1982. Hispanics increased from 2.0 to 4.4 percent between 1970 and 1982; Asian Americans from 1.0 to 2.7 percent.[8]

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[1] *Statistical Abstract, 1982-1983* (Washington, DC: U.S. Department of Commerce, Bureau of the Census, 1984), p. 159, corrected to include unclassified pre-baccalaureates; and *The Condition of Education* (Washington, DC: National Center for Education Statistics, 1985), p. 98.

[2] *The Condition of Education* (Washington, DC: National Center for Education Statistics, 1984), p. 72.

[3] *Projections of the Population* (Washington, DC: U.S. Department of Commerce, Bureau of the Census, 1984), p. 7.

[4] *Statistical Abstract* (Washington, DC: U.S. Department of Commerce, Bureau of the Census, 1985), p. 149.

[5] *Condition of Education*, op. cit., 1985, p. 79.

In sum, from 1960 to 1983, the number of undergraduates increased by a factor of 3.3, from 3.3 to 10.9 million. About 60 percent of that change was due to demographics: a 1.9-fold increase in the number of 18 to 24 year olds. The remainder was caused by an increase in the rate at which high school graduates, especially adult women and minorities, chose to participate in higher education. These enrollment trends tended to favor public over private institutions and 2-year colleges over 4-year colleges. Enrollments in public institutions increased by a factor of 4.2 (from 2.3 to 9.7 million) in the 23-year period; enrollments in 2-year colleges increased more than sevenfold (from 650,000 to 4.7 million).[9]

BACCALAUREATES

The doubling in the enrollment of undergraduates in the 1960s was accompanied by a doubling in the number of bachelor's degrees awarded in the course of the decade. In 1960, 395,000 students received B.A.s and B.S.s from the Nation's colleges and universities; by 1970 that number had increased by 112 percent to 840,000.[10]

The 1970s saw a very different pattern. Although the number of undergraduates increased by 47 percent between 1970 and 1983, the number of baccalaureates only increased by 16 percent (from 840,000 to 970,000).[11] The number of awards below the bachelor's degree granted in occupational curricula (business and commerce technologies, data processing technologies, health services and paramedical technologies, mechanical, engineering, and electronic technologies) increased 160 percent (from 154,000 to 400,000).[12] Thus baccalaureates decreased from 84.5 to 70.4 percent of the total undergraduate degrees awarded in the 1971-82 time frame.

The trend toward occupationally oriented degrees is mirrored by the changing mix of fields within the baccalaureate in the 1970s. As figure 2-1 shows, the number of bachelor's degrees in job-related fields, especially busi-

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[6] Ibid.

[7] Ibid., table 2.4, p. 94.

[8] *Statistical Abstract,* op. cit., 1985, p. 152.

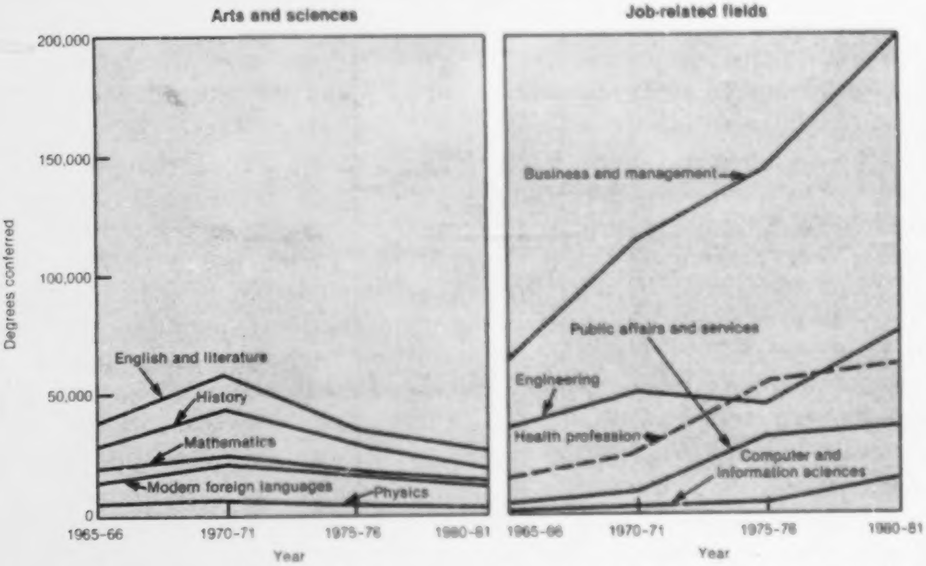
[9] *Statistical Abstract, 1982-83,* op. cit., p. 159, corrected to include non-degree credit students; and *Condition of Education,* op. cit., 1985, p. 79.

[10] *Statistical Abstract, 1979* (Washington, DC: U.S. Department of Commerce, Bureau of the Census, 1979) p. 168; *Condition of Education,* op. cit., 1985, p. 90.

[11] *Condition of Education,* op. cit., 1985, p. 90.

[12] Sue E. Berryman, "The Adjustment of Youth and Educational Institutions to Technologically-Generated Changes in Skill Requirements," prepared for the National Commission for Employment Policy, May 1985, pp. 30 and 31.

Figure 2-1.—Bachelor's Degrees Conferred in Selected Fields: United States, 1965-66 to 1980-81



SOURCE: U.S. Department of Education, National Center for Education Statistics, *Digest of Education Statistics, 1983-84*, p. 119.

ness and management, increased dramatically in the 1970s, while arts and sciences degrees declined substantially.[13] According to the National Center for Education Statistics (NCES):[14]

> In 1965-66 degrees in English and literature, history, mathematics, modern foreign languages, and physics constituted 20.4 percent of all bachelor's degrees conferred . . . . by 1980-81 they had declined to 7.4 percent of the total . . . .
>
> In 1965-66 degrees in business and management, engineering, the health professions, public affairs and services, and computer and information sciences comprised 22.6 percent of the total bachelor's degrees conferred . . . . in 1980-81 [they were] 41.8 percent . . . .
>
> At least one occupationally oriented field has not participated in the general rise in recent years. Bachelor's degrees in education . . . peaked at 194,000 in 1972-73 and subsequently declined by 44.3 percent to 108,000 in 1980-81. There has been an annual decrease in public school enrollments for a decade, and this has adversely affected the demand for new elementary and secondary school teachers.

At first glance it appears that science and engineering fields have been immune from these striking changes in undergraduate career preferences. According to the National Science Foundation (NSF),[15] science and engineering fields represented approximately 30 percent of the bachelor's and first professional degrees awarded every year from 1952 to 1982. In no year have they exceeded 32 percent or fallen short of 28 percent. (Unfortunately, the NSF tables and charts include first professional degrees, such as the M.D., D.D.S, D.V.M, and J.D., with bachelor's degrees, so the numbers are not strictly comparable to those presented above.) The total number of science and engineering bachelor's degrees and first professional degrees has remained within the 280,000 to 305,000 range since 1972.

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[13] *Digest of Education Statistics, 1983-1984* (Washington, DC: National Center for Education Statistics, December 1983), p. 119.

[14] Ibid., p. 118.

[15] *Science and Engineering Personnel: A National Overview*, NSF 85-302 (Washington, DC: National Science Foundation, 1985), p. 154.

This apparent constancy, however, masks some striking changes taking place within and between fields (see figure 2-2). From 1960 to 1974 the percentage of total B.A.s and first professional degrees awarded in the physical sciences and engineering fell from 4.1 and 9.6 percent, respectively, to 2.1 and 4.3 percent. That decline was accompanied by an increase in the percentage of degrees awarded in the social sciences from 8.0 to 14.4 percent. Between 1974 and 1982 the trend reversed itself, and engineering degrees increased from 4.3 to 6.5 percent of the total, while social science degrees fell from 14.4 to 10.9 percent.[16]

Science and engineering baccalaureates, therefore, appear to follow the same trends as total baccalaureates; increasing with total college enrollments through the 1960s and then going up only very gradually in the 1970s and early 1980s. Individual fields, however, follow changes in undergraduate interests, such as the shift from the natural sciences to the social sciences in the 1960s and from academic subjects to job-oriented subjects in the 1970s.

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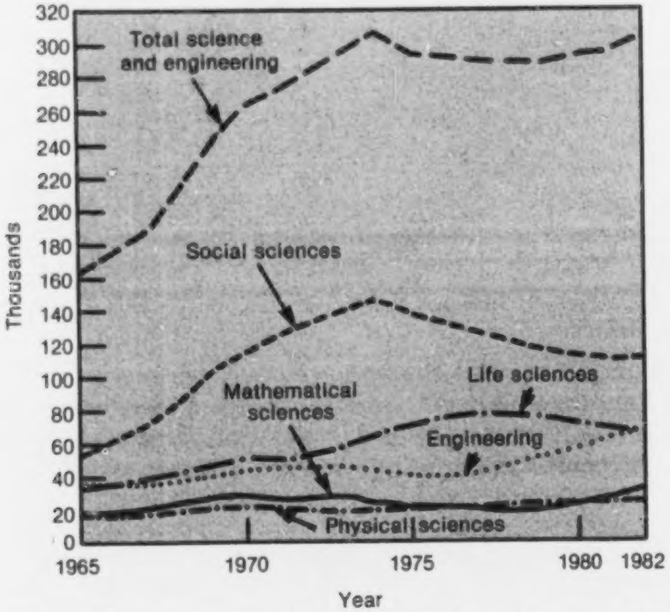
[16] Ibid.

Figure 2-2.—Bachelor's and First-Professional Degrees in Science and Engineering



SOURCE: National Science Foundation, *Science and Technology Resources*, NSF 85-305, 1985, p. 73.

It is a combination of demographic forces and career and educational choices (strongly influenced by market considerations) that determines the number of bachelor's degrees that will be produced in a science or engineering field in a given year.

FUTURE TRENDS: DEMOGRAPHICS

According to demographer Harold Hodgkinson, three major demographic trends will affect colleges and universities over the next quarter century. The first is the already cited decline in the population of 18 to 24 year olds:[17]

> Higher education can look forward to a general decrease in the size of high school graduating classes for 16 years, followed by increased numbers of high school graduates beginning in 1998 . . . .

Most recent Census Bureau projections (Middle Series) indicate that the number of 18 to 24 year olds will decline from 30.4 million in 1982 to 23.3 million in 1996, a 23.4-percent decrease.[18] This is the group that participates at the highest rate in higher education. As can be seen from table 2-1, for every 100 members of the 18- to 21-year-old population there are 27 full-time equivalent (FTE) students in higher education. (The number of "full-time equivalent students" is equal to the number of full-time students plus one-third the number of part-time students.) The ratio for 22 to 24 year olds is 11.5, and the ratios for all other age groups are much lower.[19]

Using the ratios in table 2-1 and the Census Bureau Middle Series projections of the population by age group,[20] it is relatively straightforward to construct a table of potential FTE enrollments in higher education for the rest of the century (and even to the year 2020, if one is willing to accept population projections based on births that have not occurred yet). Figure 2-3 shows a continued decline in FTE enrollments through 1996, with the minimum in that year at 85 percent of the peak in 1981. Enrollments then

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[17] Harold Hodgkinson, "College Students in the 1990's: A Demographic Portrait," *The Education Digest*, November 1983, pp. 28-31.

[18] *Projections of the Population*, op. cit., pp. 38 and 65.

[19] Carol Herring and Allen R. Sanderson, *Doctorate Employment: Supply and Demand Considerations, 1981-2000* (Princeton, NJ: Princeton University, 1981), p. 8.

[20] *Projections of the Population*, op. cit., pp. 30-81.

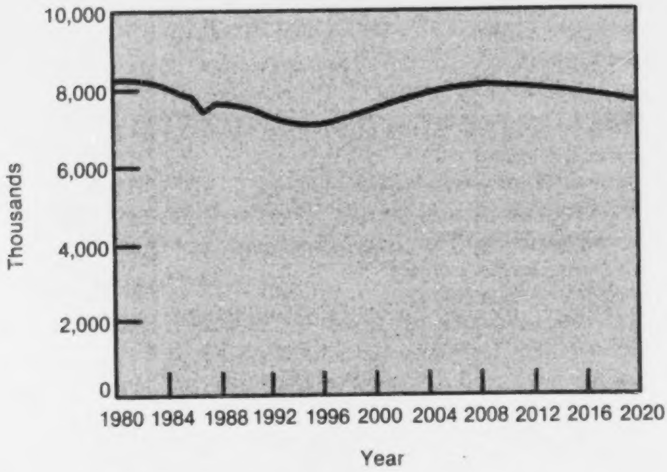
Table 2-1.—Full-Time Equivalent Enrollments

	As a percentage of the total population			
Age group	1968[a]	1973[a]	1978[a]	1980-2000[b]
17	7.1%	6.7%	5.8%	6.0%
18-21	28.0	28.0	26.0	27.0
22-24	9.7	11.2	11.4	11.5
25-29	4.0	5.0	5.0	5.0
30-34	1.9	2.5	3.0	3.0
35-59	0.4	0.6	0.8	0.8

[a] Actual.
[b] Assumed, based on current trends.

SOURCE: Carol P. Herring and Allen R. Sanderson, "Doctoral Employment: Supply and Demand Considerations, 1981-2000," Princeton University, April 1981, p. 8.

Figure 2-3.—Projected Full-Time Equivalent Students in Higher Education



SOURCES: Carol P. Heming and Allen R. Sanderson, "Doctoral Employment Supply and Demand Considerations, 1981-2000," Princeton University, April 1981, p. 8; and Office of Technology Assessment.

increase through the first decade of the 21st century, with a new peak occurring in 2010 about 15 percent above the 1996 minimum.[21]

These projections are based on a model developed by Carol Herring and Allen Sanderson that assumes existing patterns of enrollment in higher education among different age groups will continue for the next quarter century. Other assumptions could produce strikingly different results. For example, the number of 25 to 34 year olds in undergraduate education increased by nearly 70 percent in the decade 1972-82, as compared to an increase of only 23 percent in the number of 18 to 24 year olds. If this older group, which will remain relatively constant in population over the next decade, continues to increase its rate of participation in undergraduate education, it could partially offset the decline in 18 to 24 year old enrollments.[22] Specifically, if one assumes that the percent enrollments in higher education of 30 to 34 year olds and 35 to 59 year olds will continue to increase at the rates they increased between 1968 and 1978 (0.1 and 0.04 percent per year), it would generate an additional 1 million full-time equivalents in 1996. The decline of 15 percent in FTEs between 1981 and 1996 would become a much less problematic decrease of only 2.4 percent.

Herring and Sanderson argue against these more optimistic assumptions:[23]

> There are those who . . . argue that the growth in "non-traditional" enrollments will more than compensate for the loss of the traditional population base in higher education. We disagree . . . . The recent increase [in non-traditional enrollments] has been due in large measure to women going back to school, and at the present time they make up about half of the enrolled

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[21] FTEs through 2000 calculated by Herring and Sanderson, op. cit., FTEs, 2000-20 calculated by Eugene Frankel.

[22] *Digest of Educational Statistics, 1983-1984,* op. cit., p. 98.

[23] Herring and Sanderson, op. cit., p. 6.

> students. Therefore, the impact of this catching up phenomenon—in which women were making up for missed educational opportunities—is expected to level off . . . . Part of the increase in older students can also be traced to the effects of the Vietnam War and the GI Bill. These effects, too, have undoubtedly run their course, and most veterans who are going to return to school on the GI Bill have done so by now.

The NCES projection of enrollments in higher education for 1993 is consistent with Herring and Sanderson's results. It projects a drop in FTE enrollments of 12.3 percent between 1983 and 1993.[24] Herring and Sanderson also project a drop of 12.3 percent. It is worth noting that in the NCES projections the fraction of enrollments that are part time increases from 42.9 percent in 1983 to 48.3 percent in 1993.

The second major trend noted by Hodgkinson is the increasing proportion of the college age population that will be made up of racial or ethnic minorities:[25]

> The major decline in births after the baby boom was almost completely a Caucasian phenomenon. Birthrates for minorities stayed even during those years, resulting in an increased percentage of births coming from minorities . . . . The conclusion for higher education is inescapable: American public schools are now very heavily enrolled with minority students, large numbers of whom will be college eligible . . . . Out of sheer self-interest, it behooves the higher education community to do everything to make sure that the largest possible number of minority students do well in public school . . . . By 1990, minorities of all ages will constitute 20 to 25 percent of our total population, while their percentage among youth cohorts will be over 30 percent. In some states, minorities will be over 45 percent of the state birth cohorts.

Public school enrollments in 1980 presage these trends. Of the 46 million students enrolled in the Nation's public elementary and secondary schools in 1980, 26.7 percent were minority. Of the largest minority groups, blacks represented 16.1 percent of enrollments, Hispanics, 8.0 percent.[26] Seven States and the District of Columbia had minority student populations in excess of 35 percent; 11 others exceeded 25 percent (see figure 2-4).[27] In addition, 23 of the 25 largest city school systems in the Nation had a majority minority population in 1980.[28]

The report of a 1983 forum on "The Demographics of Changing Ethnic Populations and Their Implications for Elementary-Secondary and Postsecondary Educational Policy" concludes that:[29]

> Based on the demographic data . . . it seems clear that much greater attention will have to be paid to the needs of minority young people, and to the development of programs that are more responsive to their backgrounds and interests, for facilities and equipment to sustain these programs, and for teachers

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[24] *The Condition of Education*, op. cit., 1985, pp. 96 and 100.

[25] Hodgkinson, op. cit., p. 29.

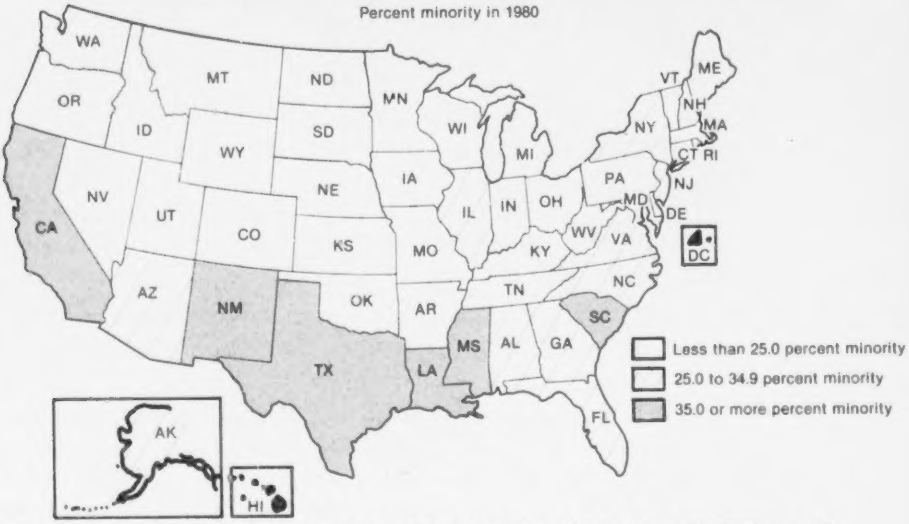
[26] *The Condition of Education*, op. cit., 1985, p. 18.

[27] Ibid., pp. 18 and 19.

[28] Ian McNett, "Demographic Imperatives: Implications for Educational Policy," Report of the June 8, 1983, Forum on "The Demographics of Changing Ethnic Populations and Their Implications for Elementary-Secondary and Postsecondary Educational Policy," p. 10.

[29] Ibid., p. 20.

Figure 2-4.—Minority Enrollment As Percent of Public Elementary/Secondary School Enrollment, by State



SOURCE: National Center for Education Statistics, *The Condition of Education, 1984 Edition*, p. 19.

> specifically trained to teach particular populations. . . . More research is needed into how young people of different backgrounds learn, and existing research should be mined and adapted for practical application to local conditions.

A third trend noted by Hodgkinson and others is the striking variation in population growth from region to region. As can be seen from figure 2-5,[30] the number of high school graduates is expected to decrease between 1981 and 2000 in the North, East, South, and Central sections of the country, while increasing in the West, Far West, and Southwest. Moreover, some of the increases (in Wyoming, Nevada, Utah, Texas, and Alaska) will be as large as 48 to 76 percent, while some of the decreases (in Michigan, Massachusetts, New Hampshire, Rhode Island, Delaware, and District of Columbia) will be as great as 30 to 51 percent.[31]

> Thus [according to Hodgkinson] we are faced for the first time with a "two nation" perspective on educational policy—trying to get more educational facilities and services for youth in the Sun Belt, and continuing to cut back on these same services in the Frost Belt. It is hard to imagine how a single federal policy on educational assistance can be equitable in both "nations." Further, since we can expect that institutions of higher education in the Sun Belt will begin to show gains in undergraduate student populations, while the Frost Belt institutions can look forward to at least a decade of decline in enrollments, it will be very difficult to present the "needs" of higher education to the U.S. Congress by 1990.

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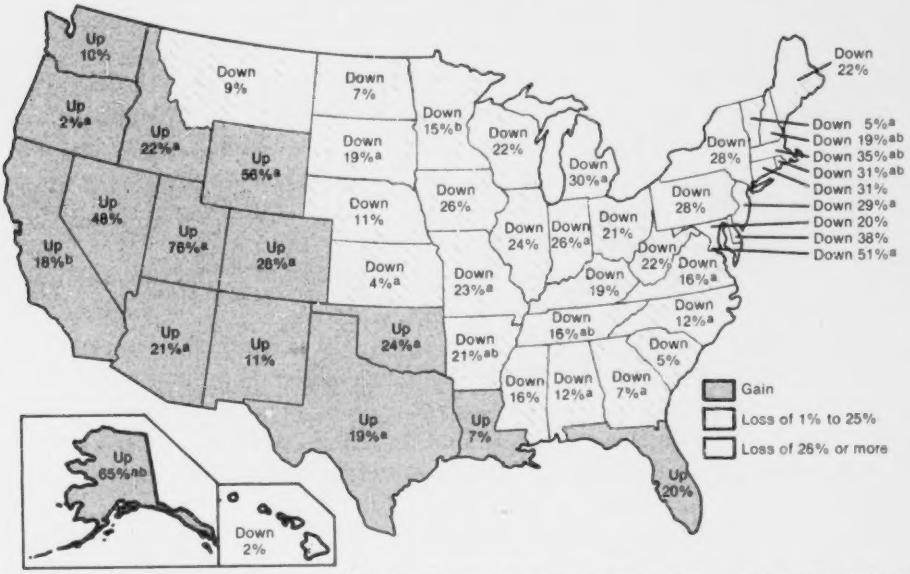
[30] Harold L. Hodgkinson, "Demographics and the Economy: Understanding a Changing Marketplace," *The Admissions Strategist*, January 1985, pp. 1-6.

[31] Hodgkinson, op. cit., 1983, p. 29.

Figure 2-5.—Projected Changes in Graduates, by State, 1981-2000



[a] Projections include graduates of public high schools only. All other State projections include public and non-public high school graduates.

[b] Projections are for 1998-99.

SOURCES: Western Interstate Commission for Higher Education, and Harold L. Hodkinson, "Demographics and the Economy: Understanding a Changing Marketplace," *The Admission Strategist*, January 1985, p. 3.

IMPLICATIONS FOR SCIENCE AND ENGINEERING PERSONNEL AND EDUCATION POLICY

The implications of these trends for science and engineering education appear to be the following: As the number of college graduates available for science and engineering careers decreases, it will become increasingly important to ensure that all potential resources are utilized to the fullest extent possible, and that no qualified candidates for science and engineering education are discouraged by problems related to gender, race, or ethnic background. Hence, policies to promote equality of opportunity for women and minorities will take on increasing relevance to science and engineering "manpower" policy.

Blacks and Hispanics may be of special concern. They tend to participate in higher education at half the rate of their white counterparts, and tend to select quantitative fields as majors once in college or graduate school at one-half (for blacks) to three-fourths (for Hispanics) the rate of the white student population.[32] As the fraction of the college age population increases, programs to promote equality of access to science and engineering careers for minority groups may have to be expanded in order to prevent a decline in the number of science and engineering degrees awarded. These programs will be discussed in greater detail in chapter 5.

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[32] Sue E. Berryman, *Who Will Do Science* (New York: The Rockefeller Foundation, 1983), pp. 18-21.

It is not possible to judge unequivocally the effects of a drop of 15 percent in the number of science and engineering baccalaureates on the Nation's scientific and technical efforts. NSF data displayed in table 2-2 show that only 43 percent of the science and engineering baccalaureates in 1980 and 1981 were employed in a science or engineering field in 1982.[33] Of the remaining science and engineering baccalaureates, 28 percent found work outside science and engineering altogether, 21 percent went on to graduate school in science and engineering and other fields and another 5 percent were still seeking employment. Thus, it appears that the Nation is currently producing more science and engineering baccalaureates than are absolutely required by the science and engineering work force.

This finding clearly does not hold true for engineering and computer science, which showed employment rates in science and engineering of about 80 percent. However, engineering and computer sciences illustrate another important feature of the science and engineering marketplace: the extreme responsiveness of undergraduates to market signals and career opportunities. Undergraduate enrollments in both computer science and engineering have increased dramatically in the last 8 years in response to excellent job opportunities for baccalaureates in those fields, as discussed in chapter 1. If other scientific fields were to require greater numbers of technically trained

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[33] *National Patterns of Science and Technology, 1984,* NSF 84-311 (Washington, DC: National Science Foundation, 1984), p. 24.

Table 2-2.—Transition of 1980 and 1981 Science/Engineering (S/E) Graduates From School to Work in 1982 (percent)

Degree level/field	Total	Employed			Full-time graduate students	Not employed	
		Total	In S/E	Outside S/E		Seeking employment	Outside labor force
Bachelor's degrees:							
All S/E	100	71	43	28	21	5	4
Physical sciences[a]	100	53	41	12	40	4	3
Mathematics	100	80	57	23	13	4	4
Computer specialties	100	94	85	9	3	2	1
Engineering	100	89	78	10	7	3	2
Life sciences	100	58	34	24	33	5	5
Social sciences[b]	100	68	21	46	22	6	5
Master's degrees:							
All S/E	100	74	55	19	21	3	2
Physical sciences[a]	100	65	47	18	29	3	3
Mathematics	100	77	56	21	17	3	3
Computer specialties	100	88	76	12	10	1	1
Engineering	100	82	72	11	14	2	2
Life sciences	100	65	47	17	31	2	3
Social sciences[b]	100	68	34	34	24	6	3

[a] Includes environmental sciences.
[b] Includes psychology.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources*, NSF 84-311, p. 24.

baccalaureates, market signals alone would attract an increasing supply of undergraduates to them. As Sue Berryman has found:[34]

> Overall, the data on the levels and fields of completed degrees suggest that youth respond to oversupplies by earning fewer degrees in oversupplied fields. If they enter an oversupplied field, they increase the amount of education they obtain—presumably to increase their competitiveness in a loose labor market. They respond to shortages or more liberal employment opportunities by increasing their educational investments in these fields at the lower degree levels and reducing them at the higher degree levels—presumably because they are in a seller's market.

GRADUATE EDUCATION

Graduate school is the principal training ground for a research career. Here the student gains the advanced knowledge and techniques that are the tools of the research trade, and forms the professional contacts that shape a research career. A great deal of detailed information about science and engineering graduate education is available from the National Science Foundation, the National Academy of Sciences, the Institute of Medicine, and the science and engineering professional societies. Science and engineering graduate students are classified by field, degree, source of support, type of institution, sex, racial and ethnic group, and citizenship. Ph.D. scientists are probably the most thoroughly surveyed and well-documented citizens in the United States. This section summarizes the principal trends in graduate education, focusing on the doctoral degree as the entry level to a research career.

Graduate enrollments have followed a pattern similar to that of undergraduates in the past quarter century, dramatically increasing in the 1960s and then rising more modestly in the 1970s and early 1980s. However, the relationship to larger demographic trends is far more tenuous than in the undergraduate case. From 1960 to 1970 graduate enrollments nearly tripled, rising from 360,000 to over a million, while at the same time, the population of 22 to 34 year olds increased by only 18 percent.[35] From 1970 to 1982, by contrast, the number of graduate students increased only modestly, by 30 percent, while the overall population of 22 to 34 year olds rose more than 55 percent.[36] (See below.) Thus there appears to be no direct relationship between graduate enrollments and the graduate school age population.

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[34] Sue E. Berryman, "The Adjustment of Youth and Educational Institutions to Technologically-Generated Changes in Skill Requirements," op. cit., p. v.

[35] *Statistical Abstract, 1982-83*, op. cit., pp. 25 and 159.

[36] *Condition of Education*, op. cit., 1985, p. 79; *Projections of the Population*, op. cit., p. 38.

Graduate Population, Enrollments, Ph.D.s

	1960		*1970*		*1983*
Population of 22 to 34 year olds	29,250,000		34,500,000		53,600,000
(percent change)		(+18 percent)		(+55 percent)	
Total graduate enrollment	356,000		1,031,000		1,339,000
(percent change)		(+200 percent)		(+30 percent)	
S/E full-time enrollment	78,308		187,843		263,800
(percent change)		(+150 percent)		(+40 percent)	
Ph.D.s/yr., all fields	9,132		29,479		31,190
(percent change)		(+223 percent)		(+6 percent)	
S/E Ph.D.s per year	6,263		17,743		17,924
(percent change)		(+183 percent)		(+1 percent)	

Science and engineering have followed overall graduate enrollment trends quite closely. From 1960 to 1970 the number of full-time graduate science and engineering students enrolled in U.S. institutions increased 150 percent, from about 78,000 to 188,000.[37] By 1982 that number had reached 264,000, a further increase of 40 percent.[38] (An additional 150,000 science and engineering graduate students were enrolled part time, bringing the total to 414,000.[39]) Enrollment growth was greatest in the social sciences and the life sciences over the full 23-year period, as can be seen from figure 2-6, and weakest in engineering, physical science, and especially mathematics and computer science.[40]

The number of doctorate degrees awarded annually in *all* fields tripled in the decade of the 1960s, reaching a peak in 1973 at 33,755. It has subsequently declined to a level of 31,000 per year, where it has remained since 1978 (see above and figure 2-7).[41] The number of *science and engineering* Ph.D.s grew slightly less rapidly, by a factor of 2.85 between 1960 and 1970. It reached a peak at 19,009 in 1972 and has subsequently declined to a nearly constant level of 17,500 to 18,000 per year in the 1980s.[42] The share of total doctorates awarded in science or engineering decreased from 65 percent in the early 1960s to 55 percent by the late 1970s.[43]

The number of Ph.D.s awarded annually grew at roughly the same rate in all science and engineering fields during the 1960s, as can be seen from figure 2-8. In the early 1970s, however, the paths of the different disciplines began to diverge. The number of doctorates awarded annually in engineering, and the mathematical and physical sciences decreased by 30 percent

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[37] Susan Fallows, "Federal Support for Graduate Education in the Sciences and Engineering," background paper prepared for the Ad Hoc Committee on Government-University Relationships in Support of Science, National Academy of Sciences, 1983, p. 10.

[38] *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1982,* NSF 85-300 (Washington, DC: National Science Foundation, 1985), p. 20.

[39] Ibid.

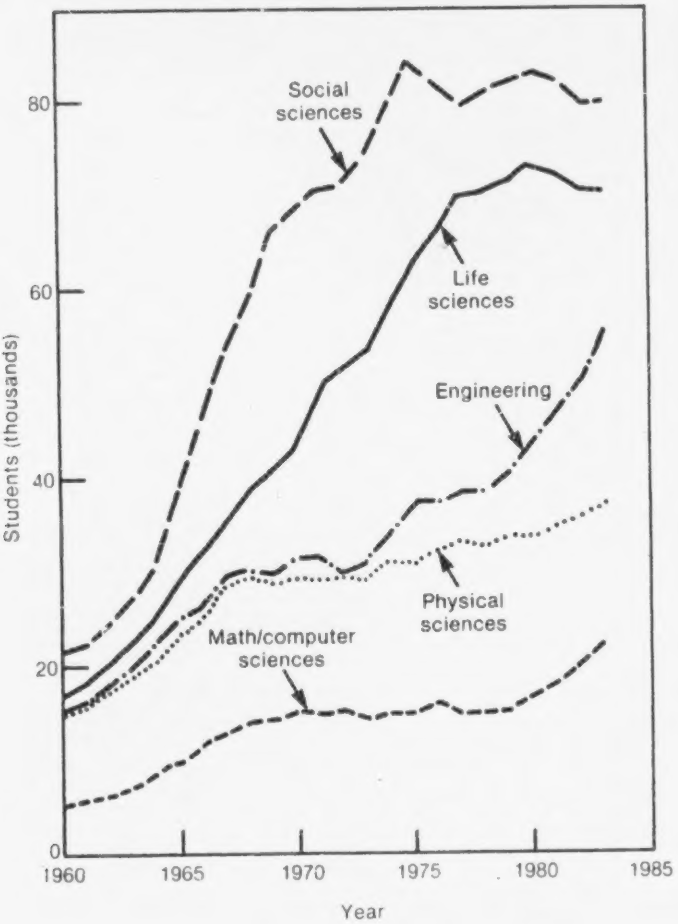
[40] Fallows, op. cit., p. 12.

[41] Ibid., pp. 31 and 32; *Science and Engineering Personnel: A National Overview,* op. cit., p. 156, gives slightly different numbers for total Ph.D.s: 9,733 in 1960; 29,498 in 1970.

[42] Fallows, op. cit., p. 31.; *Science and Engineering Personnel: A National Overview,* op. cit., again gives different numbers, 6,263 science and engineering Ph.D.s in 1960 and 17,743 in 1970. This is due to a difference in classification of life science and social science fields between the National Science Foundation and the National Academy of Sciences.

[43] *Science and Engineering Personnel: A National Overview,* op. cit., p. 156.

Figure 2-6.—Full-Time Graduate Enrollments in Science/Engineering at U.S. Institutions, by Field and by Year, 1960-83



SOURCE: Susan Fallows, *Federal Support for Graduate Education in the Sciences and Engineering* (Washington, DC: National Academy of Sciences, 1983), p. 12.

between 1971 and 1978, dropping from 4,500 to 3,200 per year in the physical sciences, from 3,500 to 2,400 in engineering and from 1,300 to 960 in mathematics and computer science. Meanwhile, the number of life science Ph.D.s remained constant at about 4,400 per year, while the number of social science Ph.D.s increased from 5,000 to 6,000 per year.[44] Since 1978 the number of doctorates awarded each year in the various science and engineering fields has remained relatively constant, with modest increases taking place in engineering and the life sciences.

The changes in graduate enrollments and annual doctorates awarded in the different science and engineering fields are related to broader changes

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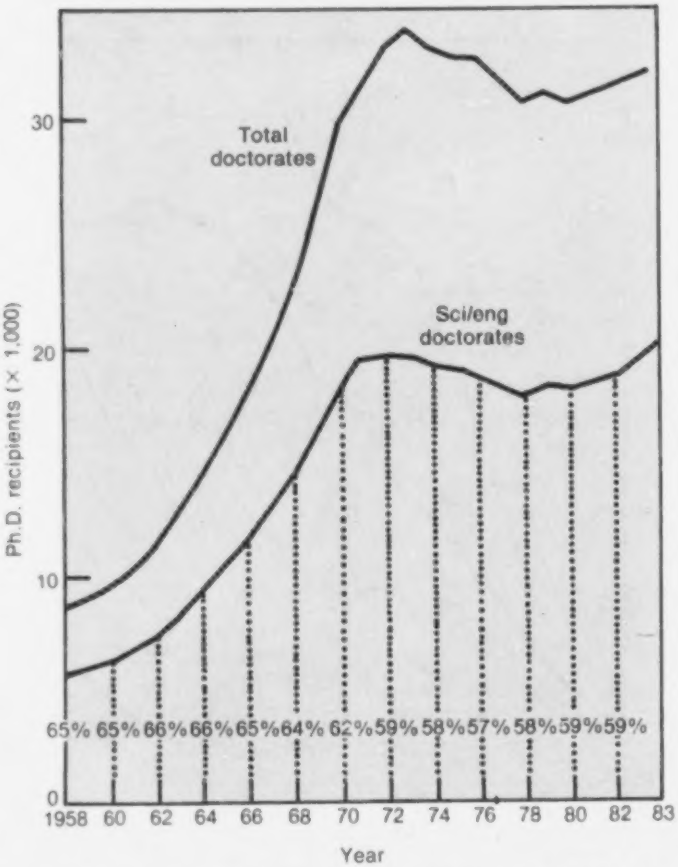
[44] Fallows, op. cit., p. 33.

Figure 2-7.—Number of Doctorates Awarded by U.S. Institutions, by Field and by Year, 1958-83



SOURCES: Susan Fallows, *Federal Support for Graduate Education in the Sciences and Engineering* (Washington, DC: National Academy of Sciences, 1983), p. 12; and National Research Council, *Doctoral Recipients From United States Universities, Summary Report, 1983*, p. 5.

in the composition of the graduate school population since 1970. Women and foreign nationals have dramatically increased their shares of both enrollments and doctorates over the past 15 years, with the effects varying from field to field. According to educational consultant Robert Snyder:[45]

> It is important to note that graduate science and engineering enrollments would have remained flat, were it not for the marked increases in female and foreign enrollments. With respect to gender differences, female full-time enrollment in doctoral institutions rose 53 percent in the 1975-1982 time period, compared to level enrollment for men. While sharp percentage increases occurred in engineering, environmental and computer sciences, these increases were built upon a meager base. Therefore, as of 1982, women comprised only 11 percent of full-time engineering students, 20 percent in physical/environmental sciences and 25 percent in mathematical/computer sciences. The greatest

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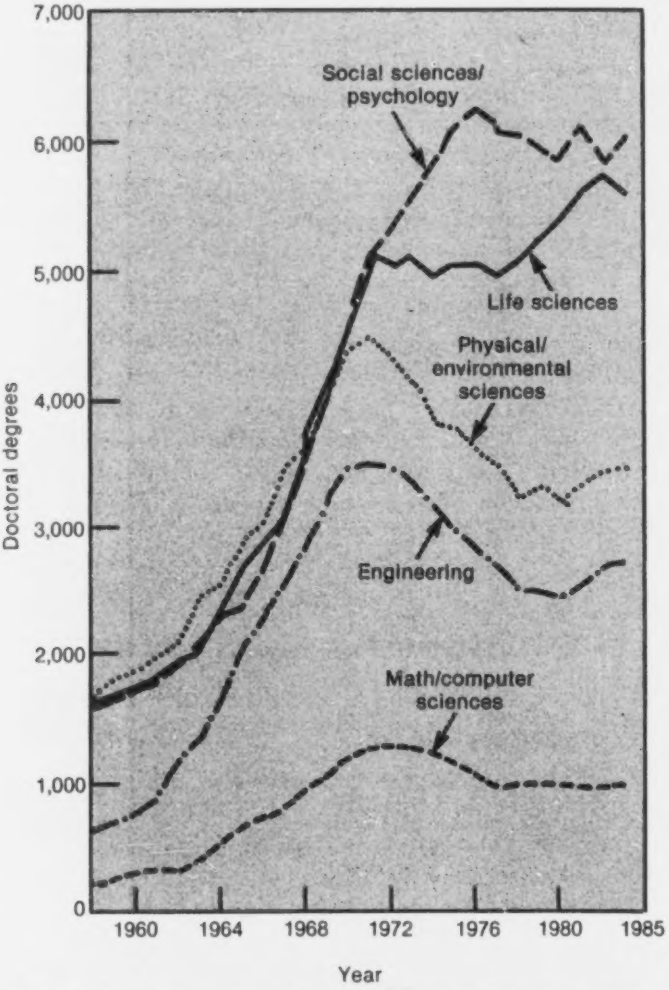
[45] R.G. Snyder, "Some Indicators of the Condition of Graduate Education in Science and Engineering," paper presented at The Brookings Institution, Nov. 15, 1984, typescript, pp. 4-5.

Figure 2-8.—Doctorate Degrees in Science and Engineering by Field and by Year, 1958-83



SOURCES: Susan Fallows, *Federal Support for Graduate Education in the Sciences and Engineering* (Washington, DC: National Academy of Sciences, 1983), p. 12; and National Research Council, *Doctoral Recipients From United States Universities, Summary Report, 1983*, p. 5; and National Science Foundation, *Science and Technology Resources*, NSF 85-305, January 1985, pp. 63-65.

impact of female enrollment increases has been in the biological sciences (40 percent women) and psychology/social sciences (46 percent women). In fact, *male* full-time enrollment in the 1975-82 period declined 14 percent in the biological sciences and 17 percent in psychology/social sciences compared to *female* increases of 38 and 35 percent, respectively, in the same period. Thus female enrollments were wholly responsible for positive enrollment trends in these two broad fields.

In [the "EMP" sciences], enrollment increases have been due significantly to surging enrollments of foreign students. In engineering, foreign full-time enrollments rose at an average annual rate of 8.4 percent from 1975 to 1982, reaching almost 21,000 students or 43 percent of total full-time students in this broad field. This compares to an annual increase among U.S. citizens of only 1.6 percent. An even larger discrepancy was in mathematics/computer sciences. Here, foreign enrollments increased at a rate of 12.7 percent per year, to a 36 percent share of full-time enrollments, compared to a 0.5 percent per year increase for U.S. citizens. One encouraging note is that in 1981-82, the most recent year for which data are available, U.S. enrollments in both these broad fields rose at much higher rates than previously.

With respect to minority participation in graduate science and engineering education, the picture in recent years is not encouraging. While extended trend data are not available, recent NSF data show very low rates of participation. For all fields, blacks comprise only 2.5 percent and Hispanics 2.1 percent of full-time science and engineering enrollments in 1982.

Data on doctoral degree production confirm these trends. Figure 2-9 shows the dramatic increases in percentage of Ph.D.s awarded to women in all fields between 1965 and 1983.[46] Table 2-3 shows the dramatic increase in the percentage of science and engineering doctoral recipients who were foreign nationals on temporary visas between 1970 and 1983 in physics/astronomy, chemistry, mathematics, and engineering. The first two fields increased by more than a factor of 2; the last two by a factor of 3.[47]

FEDERAL SUPPORT FOR GRADUATE EDUCATION IN SCIENCE AND ENGINEERING

The pattern of graduate enrollment and Ph.D. production in science and engineering in the 1960-75 era is also related to the changing nature and

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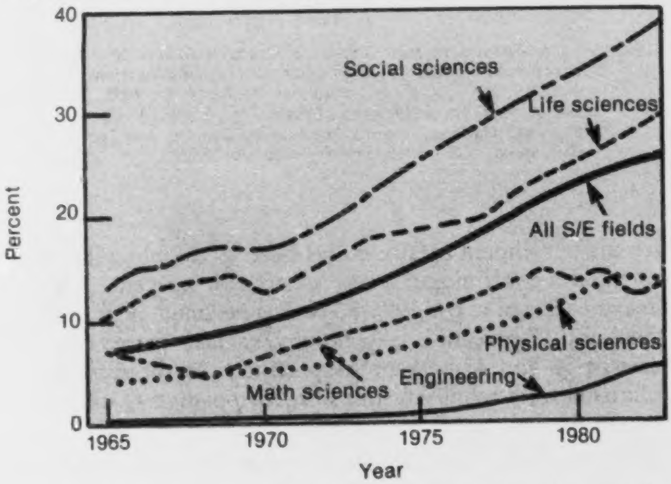
[46] *Opportunities in Science and Engineering* (Washington, DC: Scientific Manpower Commission, 1984), p. 8.

[47] *Professional Women and Minorities* (Washington, DC: Scientific Manpower Commission, August 1984), p. 32.

Figure 2-9.—Percent of S/E Ph.D.s Earned by Women



SOURCE: Scientific Manpower Commission, *Opportunities in Science and Engineering*, Washington, DC, 1984, p. 8.

Table 2-3.—Percent of S/E Doctoral Recipients Who Were Foreign Nationals on Temporary Visas, Selected Years

Field	1962	1966	1970	1974	1980	1983
Physics/astronomy	13.7%	12.2%	11.3%	17.2%	19.2%	24.6%
Chemistry	9.7	11.1	7.9	10.2	15.4	16.1
Eartn/environmental science	9.2	12.9	13.9	16.1	12.7	16.6
Mathematics	16.8	12.6	10.9	18.5	18.7	29.8
Economics	17.2	20.1	17.2	22.0	25.0	25.9
Political science	19.1	13.0	9.3	10.8	11.9	13.9
Engineering	17.9	16.7	13.7	22.4	34.3	42.1
Biological science	14.4	14.3	10.5	10.5	7.8	8.6
Medical science	14.6	18.6	16.6	9.4	11.3	13.7
Agricultural science	23.8	30.4	25.3	33.2	32.6	31.2
Total S/E	15.2%	15.3%	12.5%	16.7%	18.8%	15.5%

SOURCE: Scientific Manpower Commission, *Professional Women and Minorities*, Washington, DC, 1984, p. 32.

level of Federal support for graduate education in those fields. Since World War II, the Federal Government has utilized a variety of mechanisms to support graduate students and further the goal of enhancing the Nation's resources of highly trained scientists and engineers. Fellowships and traineeships are the direct forms of support for graduate students that have been most frequently used to target areas of perceived personnel need. Research grants and institutional support have also provided essential, though indirect, means of supporting graduate education.

Fellowships are tuition/stipend mechanisms that are awarded directly to students through national competition. Award is made principally on the basis of merit, the intent being to attract the best students available into a particular field or problem area. Fellowships are portable in the sense that the awardee is free to enroll in any qualified institution to which he/she can gain admittance.

Federal traineeship programs (sometimes called "training grants"), in contrast to fellowships, are blocks of student tuition/stipend awards that are made to departments or institutions on a multi-year basis. Traineeships focus on the training program, not the student. Departments typically apply for training grants in national competition, and awards are made by peer review so that high quality standards are met. Because of the multi-year block nature of training grants, they are well suited to target personnel at social problem solving areas as well as broad fields of science. The National Institutes of Health (NIH) training grants, historically the largest of these programs, have been used for both purposes.

Federal research grants are an important vehicle for training and support of graduate students through the research assistantship (RA). Since research training is generally acquired through an apprenticeship with a faculty member, the RA aids in this mentoring process, while providing a source of financial support for the student. However, since the primary purpose of the RA is to assist in the production of research, the number of RAs awarded is often not explicitly related to national personnel and training requirements.

A final source of Federal support for graduate education is the institutional grant, such as the general science support grant, facilities and equipment support, and the science development grant. Most of these forms of assistance do not support graduate students directly, but undergird the research and education environment.

Prior to 1958, the primary source of Federal assistance to graduate education in science and engineering was the research assistantship. According to education consultant Robert Snyder, "a survey of graduate student support in 1954 by NSF indicated that 10 percent of all graduate students received Federal stipend support (6,751), of which 86 percent came in the form of research assistantships." By 1969, the situation had changed dramatically: 36 percent of all graduate science and engineering students (51,620) were supported by the Federal Government, and 56 percent of those supported held either a fellowship or a traineeship. Table 2-4 illustrates those changes.[48]

The impetus for this change was the launching of Sputnik by the Soviet Union in October 1957. The following year Congress passed the National Defense Education Act (NDEA, Public Law 85-864) which "marked the inception of large-scale Federal graduate education support."[49] The Title IV fellowship program of NDEA grew to support more than 15,000 graduate students at a budget of $86 million in 1968, with support being provided in many academic fields, including the heretofore excluded humanities.[50] In addition, NDEA also "provided subsidies to educational institutions to

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[48] Robert G. Snyder, "Federal Support of Graduate Education in the Natural Sciences: An Inquiry Into the Social Impact of Public Policy," doctoral dissertation, Syracuse University, June 1981, pp. 103 and 110; appendix tables 6 and 9, pp. 264 and 267.

[49] Ibid., p. 108.

[50] Ibid.

Table 2-4.—Distribution of Primary Sources of Support for Full-Time Science and Engineering Graduate Students in Doctorate-Granting Departments, Selected Years

Source of support	1954	1966	1969	1974	1979	1983
Number of graduate students:						
All sources	67,136	118,273	141,199	195,915	223,409	243,646
Federal Government	6,751	44,612	51,620	48,016	52,871	47,402
Institution/State	16,958	42,343	50,471	75,411	82,813	96,188
Self	39,000	19,571	26,307	56,085	67,686	75,641
Other	4,427	11,747	12,801	16,403	20,039	24,415
Percent distribution:						
All sources	100.0	100.0	100.0	100.0	100.0	100.0
Federal Government	10.1	37.7	36.6	24.5	23.7	19.5
Institution/State	25.3	35.8	35.7	38.5	37.1	39.5
Self	58.1	16.6	18.6	28.6	30.3	31.0
Other	6.6	9.9	9.1	8.4	9.0	10.0

NOTE: Except for 1979 and 1983, *absolute* numbers in this table should be used with caution for trend analysis, because they are derived from somewhat incompatible sources. 1954 data include part-time students, thereby overrepresenting self-support.

SOURCES: National Science Foundation, *Graduate Student Enrollment and Support in American Universities and Colleges, 1954;* National Science Foundation, *Graduate Student Support and Manpower Resources in Graduate Science Education,* fall 1966 and fall 1969; National Science Foundation, *Academic Science Graduate Enrollment and Support, Fall, 1978;* and National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983.*

create low interest loans for needy students in all disciplines . . . . [which] would be forgiven for students who later went into teaching careers."[51]

In the years following the passage of NDEA, the President's Science Advisory Committee issued a series of reports calling for increased support for science and engineering education. These reports—*Education for the Age of Science* (1959); *Scientific Progress, the Universities and the Federal Government* (the "Seaborg report," 1960), and *Meeting Manpower Needs in Science and Technology* (the "Gilliland report," 1962)—"articulated the national need for greater numbers of scientists and engineers . . ., and for stronger Federal support for the training of manpower for basic research and for university level teaching."[52] They were followed by a set of significant actions:

1. The NSF fellowship program, begun in 1952, was expanded from about 500 to 2,500 per year.
2. An NSF traineeship program was begun in 1962, and awarded 5,000 traineeships a year to 200 institutions by the late 1960s.
3. NIH predoctoral support programs expanded from 55 traineeships in 1958 to 7,696 traineeships and 1,527 fellowships in 1970.
4. The National Aeronautics and Space Administration (NASA) instituted a traineeship program in 1962 for engineers, mathematicians and physical scientists.
5. The Atomic Energy Commission (AEC) expanded its fellowship program and instituted a new traineeship program (1965) in nuclear science and engineering.

All told, the number of science and engineering graduate students supported by Federal predoctoral fellowships and traineeships increased from 5,000 in 1961 to 34,100 in the peak year of 1969.[53] (See figure 2-10.) At the same time Federal research and development (R&D) support to universities expanded fourfold, from $405 million in 1960 to $1.595 billion in current dollars in 1969.[54] As a result, the number of federally supported research assistantships increased to more than 19,600 in 1969.[55]

In addition to direct stipends for graduate study and research, two new programs in the mid-1960s broadened the scope of Federal support for graduate education. These were the Guaranteed Student Loan and College Work Study programs authorized by the Higher Education Act of 1965 (Public Law 89-329). The work study program "enabled graduate departments and researchers to hire low income students at a small fraction of the costs of the students' wages through Federal wage subsidies." The loan program was directed at low-income graduate and undergraduate students in all fields "as part of a larger shift in Federal policy towards aiding disadvantaged socioeconomic groups."[56] By 1969 more than 70,000 students were receiv-

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[51] Fallows, op. cit., p. 5.

[52] Ibid.

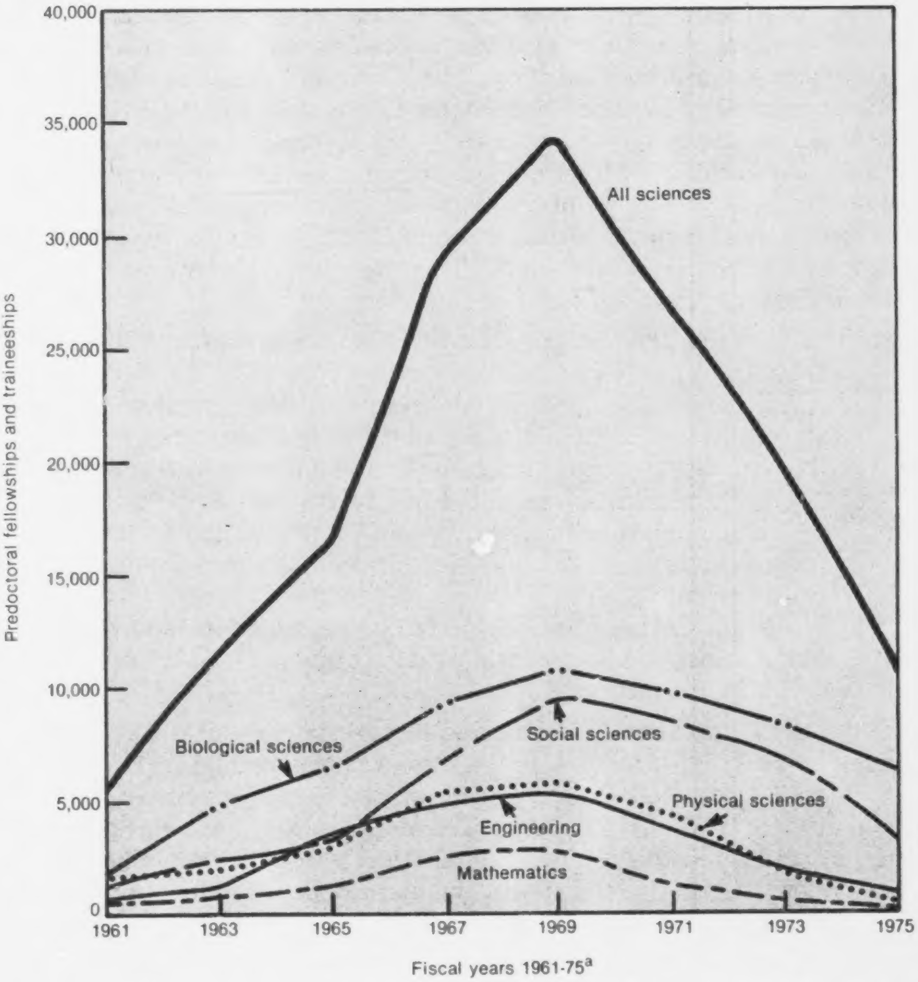
[53] Snyder, op. cit., 1981, p. 109 and appendix table 7, p. 265.

[54] Fallows, op. cit., p. 404.

[55] Snyder, op. cit., 1981, p. 267. The number 19,646 given in appendix table 9 of Snyder's dissertation represents those full-time graduate science students who indicated research assistantships as their "primary type of support." There may be other RA recipients that relied on other sources for "primary support" and are therefore not included in the total in Snyder's table.

[56] Fallows, op. cit., p. 6.

Figure 2-10.—Federal Predoctoral Fellowships and Traineeships by Field, Fiscal Years 1961-75ª



ªData include NIH training grant trainees in the biological sciences but not in other fields; data do not include NIMH trainees.
ᵇEstimate.

SOURCES: For all fields except biological sciences—FY 1961-1969 data, FICE (1970); FY 1970-1975 data, FICE (unpublished). For biological sciences—FICE (1970; unpublished) and NAS, NIH trainee file, and NIH (1978). Robert G. Snyder, *The Effectiveness of Federal Graduate Education Policy [for] Scientific Personnel*, report to Office of Technology Assessment, June 1985, table 2.

ing guaranteed student loans; 17,000 were enrolled in college work-study programs and 27,400 held NDEA loans. An additional 91,464 graduate and professional school students (the numbers are not available for graduate students alone) were supported by veterans benefits.[57] It should be noted, however, that the average level of support per student from these programs was less than $1,000 per year, as compared to more than $5,500 per year, tuition plus stipend, from the NDEA Title IV fellowship program.

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[57] Snyder, op. cit., 1981, appendix table 11, p. 269 and appendix table 12, p. 270.

Thus, between 1960 and 1969 Federal support for graduate education in science and engineering expanded dramatically, as part of an overall Federal emphasis on post-secondary education. Other forces were at work as well during this period. Increasing State support for higher education, and especially the expansion of many State university systems in this era, created an increasing demand for new faculty to instruct the growing numbers of undergraduates. And increasing undergraduate enrollments created significant additional demands for teaching assistants, thereby providing much additional graduate student support. By 1969, over 50,000 full-time science and engineering graduate students were receiving their primary source of support from institutional and State sources, nearly as many as received Federal assistance (see table 2-4). Of those students, 33,000 held teaching assistantships.[58]

With undergraduate enrollments in both public and private institutions increasing dramatically, as we have seen above, the labor market for doctoral personnel was booming in the 1960s. The 260,000 new junior faculty hired during the decade exceeded the number of doctorates awarded between 1960 and 1969—170,000—by 53 percent.[59] This situation boosted the salaries of doctorate recipients relative to other occupations, thereby providing added inducement for more people to enter doctoral study.[60] (Faculty salaries rose 50 percent faster than those of all other workers during the 1960s, according to Richard Freeman.[61])

Thus, a complex array of interconnecting variables—Federal, State, and private sector—appear to have combined to produce the surge of graduate enrollments and doctoral production in the 1960s. In addition, the Vietnam War led many male college graduates to enroll in graduate school and remain there through receipt of a degree.

The year 1969 turned out to be a watershed for Federal support of graduate education in science and engineering. A combination of political, economic, and social factors, and a growing Federal awareness that demand for doctoral scientists and engineers was not keeping up with supply, led to severe cutbacks in Federal fellowship and traineeship support. The number of U.S. Government supported fellows and trainees declined from 36,000 in 1969 to 10,800 in 1975. The NDEA Title IV fellowship program was phased out in 1973. NSF traineeships, NIH fellowships, NASA traineeships, and AEC fellowships and traineeships were all eliminated in the early 1970s. All that remained by 1979 were 4,800 NIH traineeships, approximately 1,500 Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA) traineeships and fellowships, and 1,500 NSF merit fellowships.[62]

Federal R&D expenditures at universities, which had increased by a factor of 4 in current dollars, and a factor of 3 in constant dollars, between

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[58] *Graduate Student Support and Manpower Resources in Graduate Science Education*, NSF 70-40 (Washington, DC: National Science Foundation, 1969), p. 50.

[59] Allan Cartter, *Ph.D.s and the Academic Labor Market* (New York: McGraw-Hill, 1976), p. 123.

[60] *The Demand for New Faculty in Science and Engineering* (Washington,DC: National Research Council, 1980), p. 117.

[61] Richard Freeman, *The Market for College-Trained Manpower* (Cambridge, MA: Harvard University Press, 1971), pp. 77-80.

[62] Snyder, op. cit., 1981, pp. 122 and 123.

1960 and 1968, stopped growing. In 1974 the level of Federal R&D support to universities was only 25 percent above its total 6 years earlier in current dollars, and 7.2 percent *less* in constant dollars.[63] The number of federally supported research assistantships decreased by about 10 percent between 1969 and 1974.

The effects of changing levels of Federal support on the supply of new science and engineering Ph.D.s is seen most dramatically by comparing the experience of different science and engineering fields during the contraction period, 1968-75. Figure 2-10 and table 2-5 show the dramatic drop in the number of Federal fellowships and traineeships awarded in engineering, mathematics, and the physical sciences between 1968 and 1975. The number of awards dropped from 3,000 to 200 in mathematics; from 6,000 to 600 in the physical sciences, and from 5,500 to 700 in engineering.[64] The total number of full-time students in doctorate granting departments supported by the Federal Government in engineering, mathematics, and physical science decreased by 18, 57, and 33 percent, respectively, between 1969 and 1974 as can be seen in table 2-6.[65] Figure 2-8 shows the substantial decline in Ph.D.s awarded in engineering, mathematics, and the physical sciences that occurred in the period 1972-78.[66] It should be noted that those three fields were also affected by a decline in Federal research funds awarded to universities of 20 percent in constant dollars between 1968 and 1974.[67]

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[63] Fallows, op. cit., p. 4.
[64] Snyder, op. cit., 1981, appendix table 7, p. 265.
[65] Ibid., appendix table 10, p. 268.
[66] Fallows, op. cit., p. 33.
[67] Snyder, op. cit., 1981, p. 262.

Table 2-5.—Federal Predoctoral Fellowships and Traineeships by Field, Fiscal Years 1961-75[a]

Fiscal year	All sciences	Mathematics	Physical sciences	Engineering	Biological sciences	Social sciences
1961	5,445	629	1,273	638	1,782	1,123
1962	9,245	852	1,684	860	3,911	1,938
1963	11,224	899	1,955	1,050	4,940	2,380
1964	12,757	1,024	2,461	1,402	5,337	2,533
1965	16,683	1,211	2,974	3,092	6,329	3,077
1966	21,929	1,824	4,353	4,190	7,536	4,026
1967	28,895	2,598	5,424	4,784	9,250	6,839
1968	33,901	3,024	5,960	5,507	10,161	9,249
1969	34,100	2,734	5,776	5,058	10,882	9,650
1970	30,646	2,006	4,459	4,323	11,182	8,676
1971	26,694	1,073	4,071	3,540	9,669	8,341
1972	23,579	776	3,212	2,953	8,851	7,787
1973	19,335	447	1,893	1,938	8,114	6,943
1974	13,084	343	1,183	1,225	6,111	4,222
1975	10,787	208	592	715	6,098[b]	3,174

[a] Data include NIH training grant trainees in the biological sciences but not in other fields; data do not include NIMH trainees.
[b] Estimate.

SOURCES: For all fields except biological sciences—FY1961-69 data, FICE (1970); FY 1970-75 data, FICE (unpublished). For biological sciences—FICE (1970; unpublished) and NAS, NIH trainee file, and NIH (1978). Robert G. Snyder, *The Effectiveness of Federal Graduate Education Policy [for] Scientific Personnel,* report to OTA, June 1985, table 2.

By contrast, Federal fellowships and traineeships declined, but not nearly so precipitously, in the biological and social sciences—from 11,000 to 6,000 in the former, and from 9,700 to 4,200 in the latter. Moreover, as table 2-6 shows, the total number of full-time graduate students supported by the Federal Government, including RAs and other forms of support, actually increased by 45 percent in the life sciences and remained constant in the social sciences in the period 1969-74. In addition, Federal funding of research at universities and colleges in the life and social sciences remained at the same level, in constant dollars, throughout the 1968-74 period, as opposed to the decline in engineering and the mathematical and physical sciences reported above. It is not surprising, therefore, to find that the number of Ph.D.s in the life and social sciences did not decrease in the 1970s.

The apparent correspondence between decreases in Federal educational support in particular fields and decreases in the numbers of doctoral degrees awarded several years later does not, of course, prove causality. The numbers do, however, suggest that there may be a relationship between these two variables.

From 1974 to 1980 the Federal share of support for full-time science and engineering graduate students in doctorate granting institutions remained relatively constant at about to 23 to 25 percent of the total. Since 1980 it has declined to less than 20 percent.[68] Figure 2-11 presents the percentage shares of Federal support for science and engineering graduate students as a whole and by field. Note the sizable variation from field to field, with

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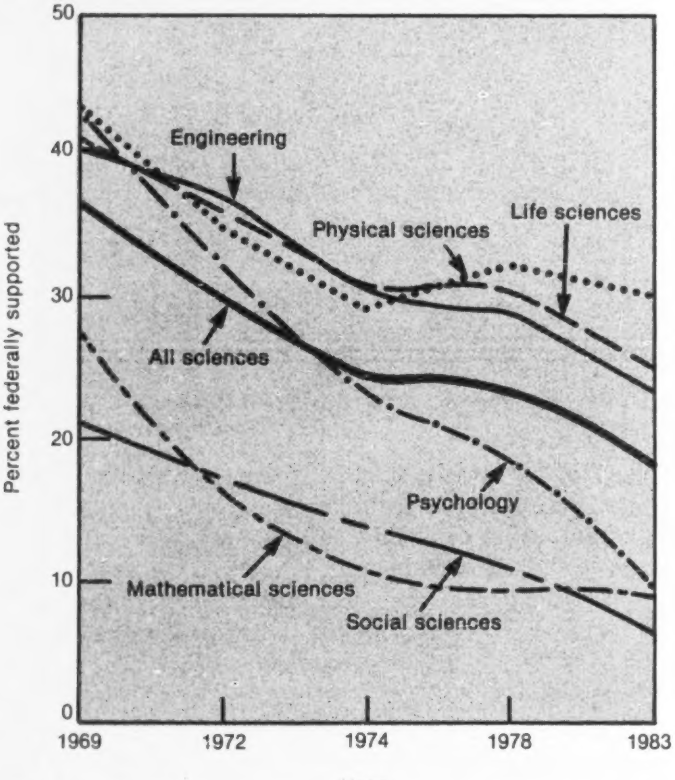
[68] Ibid., appendix table 10, p. 268; and *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1982*, op. cit., pp. 112-113.

Table 2-6.—Full-Time Graduate Students in Doctorate-Granting Institutions Supported by the Federal Government by Broad Field, Selected Years

Total full-time enrollment/ number federally supported	1969	1972	1974	1978	1983
All sciences	141,199	149,937	195,915	217,588	243,646
Federal	51,620	45,029	48,016	51,373	47,402
Engineering	30,820	30,908	33,691	37,129	53,553
Federal	12,334	11,246	10,164	10,625	11,924
Physical sciences	30,175	27,544	29,649	31,375	35,904
Federal	13,187	9,687	8,868	10,123	10,886
Mathematical sciences	11,727	11,909	13,423	13,706	19,581
Federal	3,223	1,908	1,393	1,307	1,794
Life sciences	27,588	34,083	54,800	65,097	65,185
Federal	11,513	12,037	16,757	19,659	17,221
Psychology	11,918	14,282	18,728	20,677	21,327
Federal	5,127	4,691	4,404	3,943	1,982
Social sciences	28,971	31,211	45,624	49,604	48,096
Federal	6,236	5,460	6,430	5,716	3,595

SOURCES: Robert G. Snyder, *Federal Support of Graduate Education in the Natural Sciences*, doctoral dissertation, Syracuse University, June 1981, app table 10, p. 268; and National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983*, NSF 85-300, table C14, pp. 112-113.

Figure 2-11.—Full-Time Graduate Students in Doctorate-Granting Institutions Supported by the Federal Government by Broad Field, Selected Years



SOURCES: Robert G. Snyder, *Federal Support of Graduate Education in the Natural Sciences*, Doctoral Dissertation, Syracuse University, June 1981, appendix table 10, p. 268; and NSF, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983*, NSF 85-300, table C14, pp. 112-113.

mathematics and the social sciences at 11 percent Federal support, and engineering, physical and environmental sciences, and life sciences at 20 to 30 percent.

THE FUTURE

The exact interplay of the various factors that will determine graduate enrollments and Ph.D. production in the sciences and engineering over the next 20 years is difficult to predict. It was shown above that three factors appear to influence the numbers of Ph.D.s awarded in science and engineering fields: Federal support for graduate education, State and institutional support, and demand for new doctorates. Federal support for graduate education in the sciences and engineering may rise modestly in the next decade if the funding of research grants to universities, and hence research assistantships, continues to increase. Fellowship and traineeship support will probably remain constant. State and institutional support will probably decline due to declining enrollments, with the declines being greatest in the Northeast, Middle Atlantic, and Midwestern States. However, it is also possible that science and engineering enrollments will not experience the overall declines of the rest of the higher education system and that States will continue to provide extra support for science and engineering research at their State universities as part of their efforts to develop high-technology industries for economic growth. In that case, State and institutional support may not decline at all.

As for demand, we shall see in chapter 3 that the academic demand for new science and engineering faculty is likely to be very weak over the next decade and very strong from 1995 to 2010. Industrial demand for new science and engineering Ph.D.s, by contrast, has been growing at 7.8 percent per year over the past decade and will, if it continues to grow at present rates, compensate for the decline in academic demand between 1985 and 1995. After that, if industrial demand continues to grow, there will be stiff competition between industry and academia for new scientific and engineering doctoral degree recipients in the 1995-2010 time frame. That competition will be discussed in chapter 3.

In the near-term, what is remarkable is the overall flatness of the recent trend lines, since 1978 (see figures 2-12 and 2-13),[69] for total doctorates, for doctorates in science and engineering, and for full-time graduate enrollments in science and engineering. The only exception has been engineering graduate school enrollment, which has increased dramatically, primarily at the master's level. A reasonable assumption for the next decade, which is that of the Scientific Manpower Commission and the National Center for Education Statistics (see figure 2-14),[70] is that there will be a continuation of current enrollment and Ph.D. production levels. Engineering is likely

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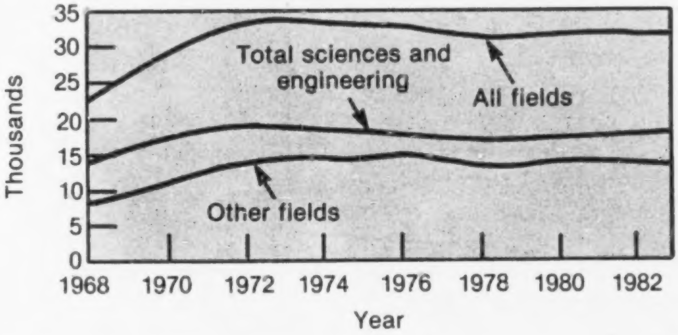
[69] *Science and Technology Resources*, NSF 85-305 (Washington, DC: National Science Foundation, January 1985), pp. 75 and 77.

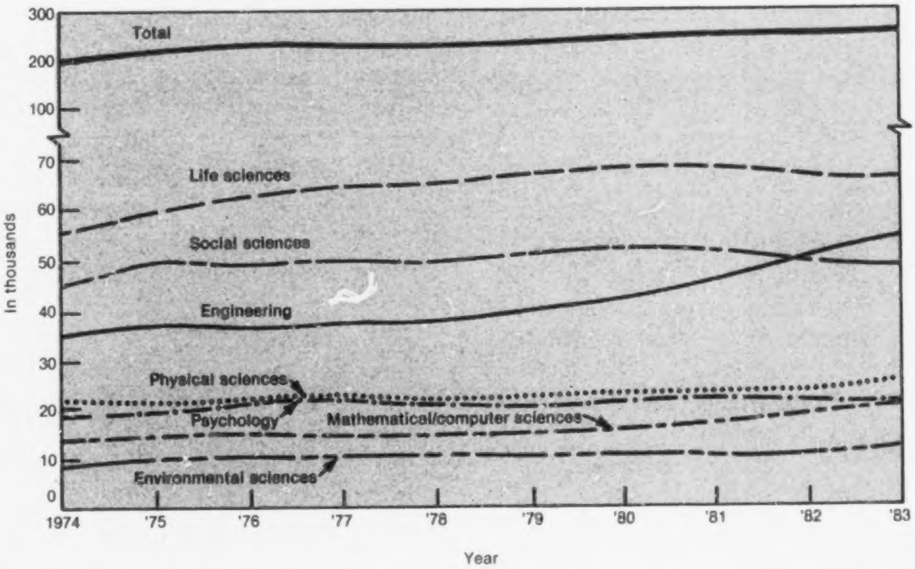
[70] *The Technological Marketplace* (Washington, DC: Scientific Manpower Commission, May 1985), p. 11; and *Condition of Education*, 1985, op. cit., pp. 128-129.

Figure 2-12.—Doctorates Awarded



SOURCE: National Science Foundation, *Science and Technology Resources*, NSF 85-305, January 1985, p. 77.

Figure 2-13.—Full-Time Graduate Enrollment by Area of Science/Engineering[a]

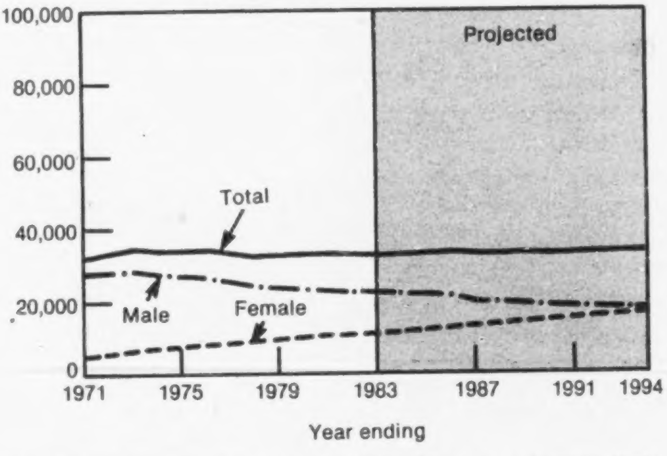


[a] In doctorate-granting institutions prior to 1974, data were collected from a selected group of departments rather than from the universe.

[b] Includes support from State and local governments.

SOURCE: National Science Foundation, *Science and Technology Resources*, NSF 85-305, January 1985, pp. 53-65.

Figure 2-14.—Trends in Doctor's Degrees Conferred, by Sex of Recipient



SOURCE: U.S. Department of Education, National Center for Education Statistics, *Condition of Education, 1985*, p. 129.

to continue to increase its share and the social sciences to decrease theirs, due to market forces. Women, whose attainment of science and engineering Ph.D.s has grown at a rate of 6.8 percent per year since 1973, are likely to increase their share of doctorates in these fields, while that of men will probably continue to decline. Foreign nationals will undoubtedly continue to be strongly represented among science and engineering Ph.D.s.

The working assumption for this document is that near-term graduate enrollments will remain constant and Ph.D. production will remain within about 10 percent of its current level. In the longer run, the strong market for science and engineering Ph.D.s that should occur at the turn of the century could lead to an increase in the number of annual doctorates awarded in those fields as students are attracted into them by career opportunities. This development will be discussed in chapter 3 when we examine the future demand for science and engineering doctoral degree holders.

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Chapter 3: Demographic Trends and the Academic Market for Science and Engineering Ph.D.s

THE NEAR-TERM DECLINE

Nowhere does a confluence of demographic trends produce more dramatic results than in the projected hiring pattern for new Ph.D.s in the Nation's universities and colleges. Two trends are at work here. First, the decline in higher education enrollments projected for the 1982-97 time period by the National Center for Education Statistics (NCES) and others (see chapter 2) should reduce the total demand for faculty proportionately. The subsequent increase in probable enrollments over the 1997-2010 period should lead to an increase in the size of the professoriat.

A second trend has to do with faculty retirements, and reflects an earlier demographic event—the spectacular growth in college faculty that accompanied the arrival of the post-World War II baby boom generation on campus in the 1960s and early 1970s. The near tripling in full-time equivalent (FTE) higher education enrollments that took place between 1960 and 1975 (from 3 to 8.5 million) was accompanied by an equivalent near tripling in the size of the full-time instructional staff (from 154,000 to 440,000).[1] This created an age distribution among college and university faculty in the late 1970s that was heavily skewed toward 35 to 40 year olds and away from 50 to 65 year olds. Figure 3-1 compares the actual age distribution of faculty in 1978 with a model age distribution that would be characteristic of a steady-state equilibrium with constant faculty size.[2] The overrepresentation of 30 to 40 year olds, and underrepresentation of 55 to 65 year olds are quite obvious.

As a result of this skewed age distribution, the rate of retirement of college and university faculty is low and will continue to remain so until the early 1990s. Figure 3-2 shows the combined death and retirement rates projected for the major science and engineering fields through the course of the century by Charlotte Kuh.[3] A "steady state" rate, assuming all faculty work for 35 years, from receipt of Ph.D. at age 30 to retirement at age 65, and no faculty growth, would be 2.5 to 3.0 percent per year.[4] It is clear

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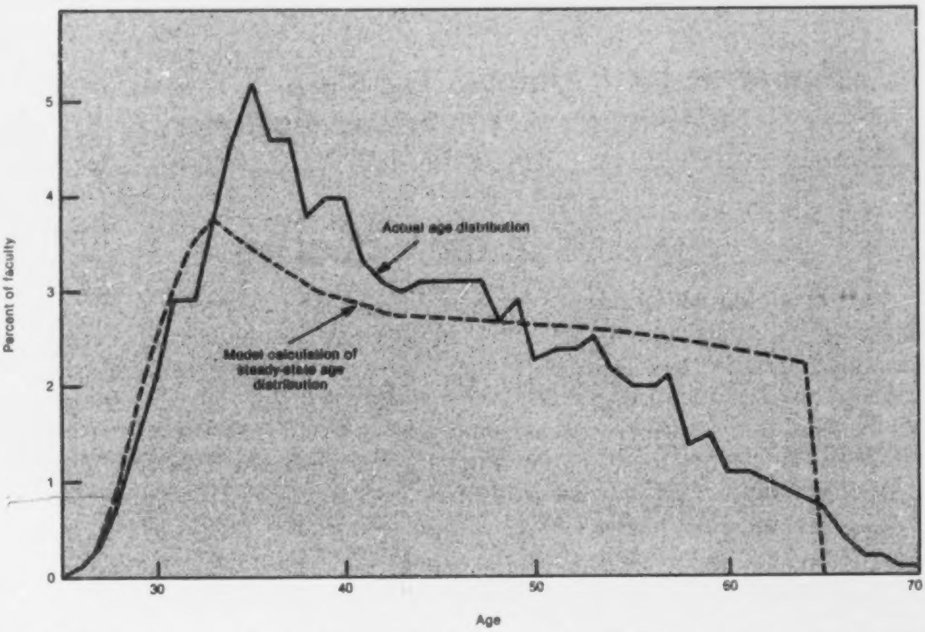
[1] American Council on Education, *1984-85 Fact Book on Higher Education* (New York: MacMillan, 1984), table 114.

[2] National Research Council, *Research Excellence Through the Year 2000* (Washington, DC: National Academy of Sciences, 1979), p. 19.

[3] Ibid., p. 23.

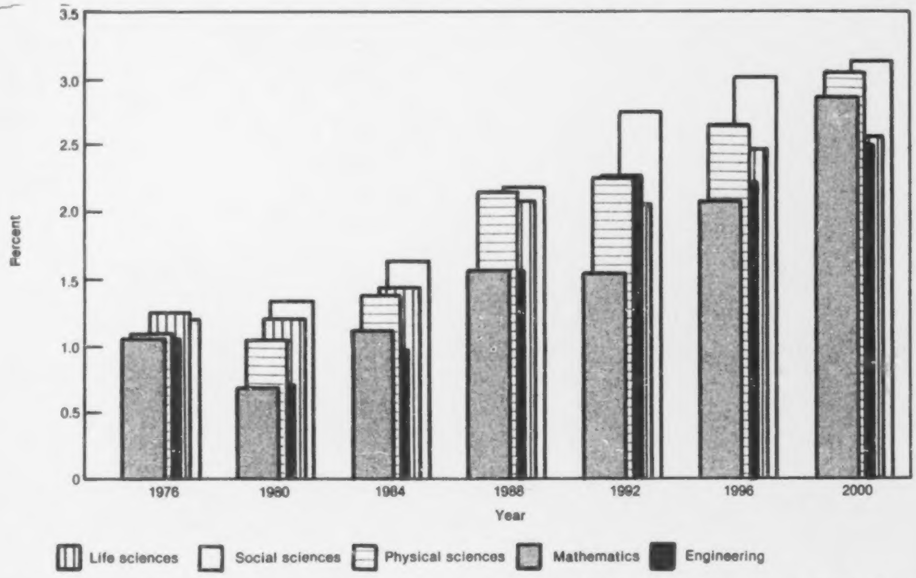
[4] Ibid., p. 24.

Figure 3-1.—Actual and Steady-State Age Distributions, Full-Time Doctoral Faculty at Ph.D.-Granting Institutions, 1978



SOURCE: National Research Council, *Research Excellence Through the Year 2000* (Washington, DC: National Academy Press, 1979), p. 19.

Figure 3-2.—Combined Death-Retirement Rate, Percent of Faculty



SOURCE: National Research Council, *Research Excellence Through the Year 2000* (Washington, DC: National Academy Press, 1979), p. 23.

that none of the fields displayed in figure 3-2 reach that rate until the 1990s, and only the social sciences surpass 2.5 percent per year before 1994. **Thus the period of low faculty retirement and death rates coincides with the period of possibly declining student enrollments.**

The confluence of these two trends leads to a period of extremely weak demand for new doctorates in academia from the early 1980s through the mid-1990s. Figure 3-3 illustrates the gap between the projected demand for new faculty, which averages 6,500 to 16,000 per year during this period,[5] and annual awards of doctoral degrees, which average about 30,000 per year. This compares quite unfavorably with the 1960s when, as shown in chapter 2, the supply of new Ph.D.s averaged 17,000 per year and the demand for faculty (including both doctoral and nondoctoral faculty) averaged 26,000 per year. It is also considerably worse than the situation in the early 1970s, when the supply of new Ph.D.s averaged 31,000 per year and the demand for faculty (growth plus replacements) also averaged about 31,000 per year, according to OTA analysis.[6] It is roughly comparable to

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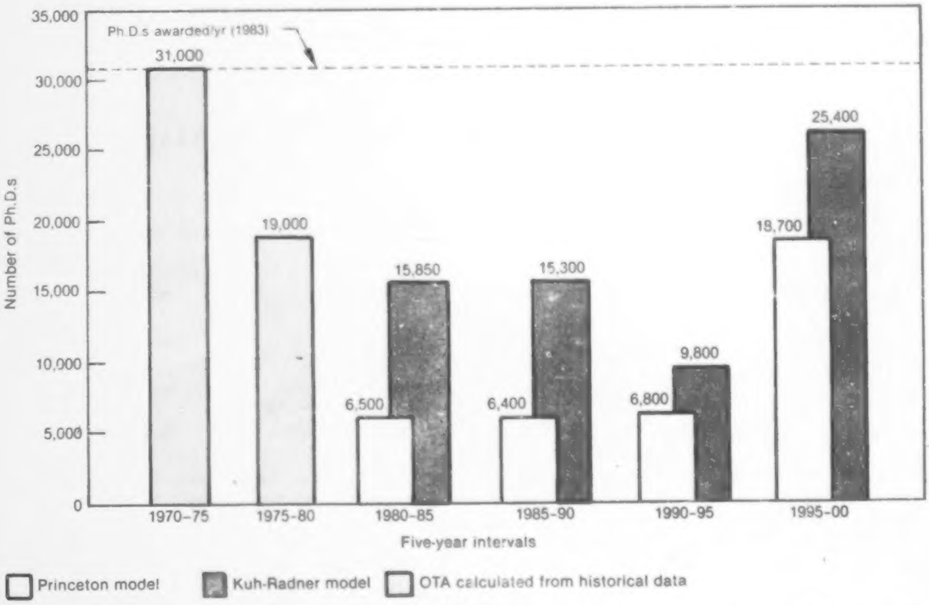
[5] William G. Bowen, *Report of the President* (Princeton, NJ: Princeton University, April 1981), p. 20; Charlotte Kuh and Roy Radner, *Preserving a Lost Generation*, report to the Carnegie Council on Policy Studies in Higher Education, October 1978, p. 9.

[6] According to the National Center for Education Statistics there were 403,700 FTE faculty employed in 1970; 502,700 in 1975 and 528,700 in 1980. That translates to growth rates of 19,800 per year between 1970 and 1975 and 5,200 per year between 1975 and 1980; U.S. Department of Education, *Condition of Education* (Washington, DC: U.S. Government Printing Office, 1985), table 2.12, p. 110. According to the National Research Council the combined death and retirement rule for faculty in the 1970s was about 1.2 percent per year; National Research Council, op. cit., p. 23. This translates into total deaths and retire-

Figure 3-3.—Annual Number of New Hires Based on Projections



SOURCES: William G. Bowen, *Report of the President* (Princeton, NJ: Princeton University, April 1981), p. 20; and C. Kuh and R. Radner, *Preserving a Lost Generation*, report to the Carnegie Council on Policy Studies in Higher Education, October 1978, p. 40.

the late 1970s, when 31,500 doctorates were awarded annually, but the number of new faculty slots averaged approximately 19,000 per year. Although over 40 percent of all science and engineering Ph.D.s enter industry or government, it is important to remember that most analysts assume that no more than 50 or 60 percent of all new faculty positions will be awarded to holders of the doctoral degree. The remainder will go to M.A.s, M.D.s, J.D.s, D.D.S.s, and other first professional degree holders.

This decline in academic positions available to new Ph.D.s was first projected in the early 1970s by Alan Cartter. His projections were refined and modified by a number of analysts, including Roy Radner, Charlotte Kuh, and Louis Fernandez[7] between 1976 and 1980, but the basic findings remained the same. Kuh and Radner were so disturbed by the implications of this finding for the careers of young scholars that they entitled their study for the Carnegie Council on Policy Studies in Higher Education, *Preserving a Lost Generation: Policies to Assure a Steady Flow of Young Scholars Until the Year 2000*.

In 1978 the National Research Council (NRC) asked Kuh and Radner to adapt their forecasts to science and engineering fields, as part of a study on *Research Excellence Through the Year 2000* (reference 2, above). Using National Science Foundation (NSF) and NRC data, Kuh and Radner prepared a set of projections for the number of new faculty hires that would be required each year from 1978 to 2000 for science and engineering as a whole, and for the major broad field categories. Those projections are summarized in figures 3-4 and 3-5 which also compare the number of new hires with the number of doctoral degrees awarded in 1983.[8] As can be seen, Kuh and Radner predict a weak academic market for science and engineering Ph.D.s from the early 1980s to the early 1990s followed by sustained growth through the year 2000. (The apparent growth in new hires in the physical sciences between 1980 and 1988 is the artifact of a spuriously high nontenured quit rate built into the model for that group.)

PROBLEMS WITH PROJECTING THE DEMAND FOR NEW FACULTY

To determine whether or not Kuh and Radners' projections of a hiring decline from 1983 to 1995 are correct it would be useful to compare their near-term (1975-83) projections with recent historical experience. Unfortu-

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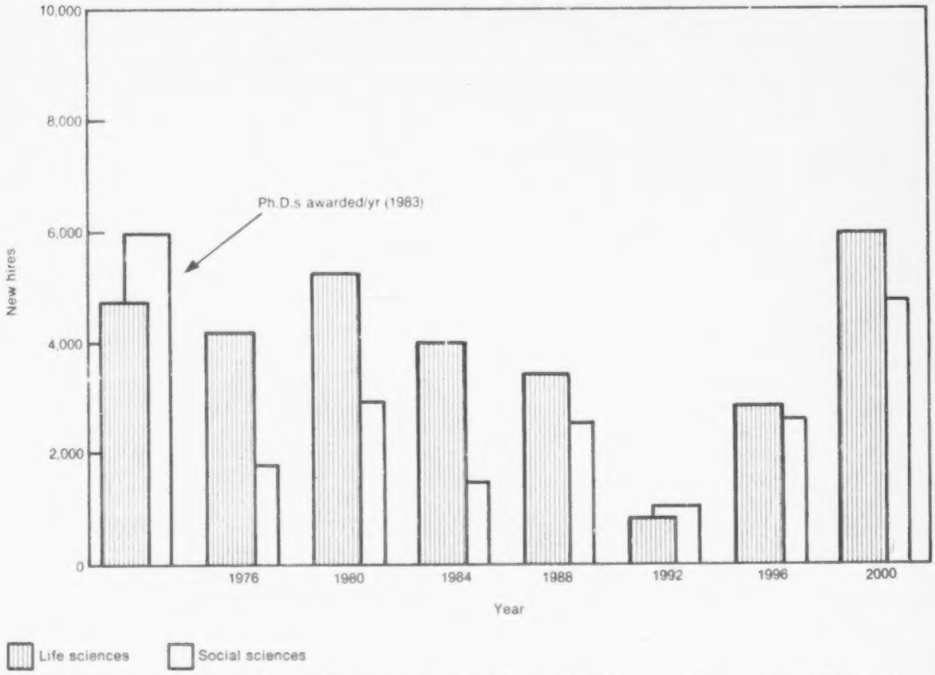
ments of 4,200 per year between 1970 and 1975 and 6,000 per year between 1975 and 1980. Charlotte Kuh and Roy Radner report tenured and nontenured quit rates of 0.5 and 4 percent per year in the mid-1970s; Kuh and Radner, op. cit., table A-4, p. 41. Using those quit rates and the ratio of tenured to nontenured faculty reported by Kuh and Radner in the same source (70:30) resignations can be estimated to be 6,300 per year from 1970 to 1975 and 7,800 per year from 1975 to 1980. Adding growth plus retirement plus resignations for each 5-year period gives the total annual demand for new faculty of 31,000 for 1970-75 and 19,000 for 1975-80 reported in the text.

[7] Alan Cartter, *Ph.D.s and the Academic Labor Market* (New York: McGraw-Hill, 1976); Louis Fernandez, *U.S. Doctorate Faculty After the Boom: Demographic Projections to 1995,* Technical Report No. 4, Carnegie Council on Policy Studies in Higher Education, October 1978; Kuh and Radner, op. cit.; Roy Radner and L. S. Miller, *Demand and Supply in U.S. Higher Education,* a report to the Carnegie Council on Policy Studies in Higher Education, 1976.

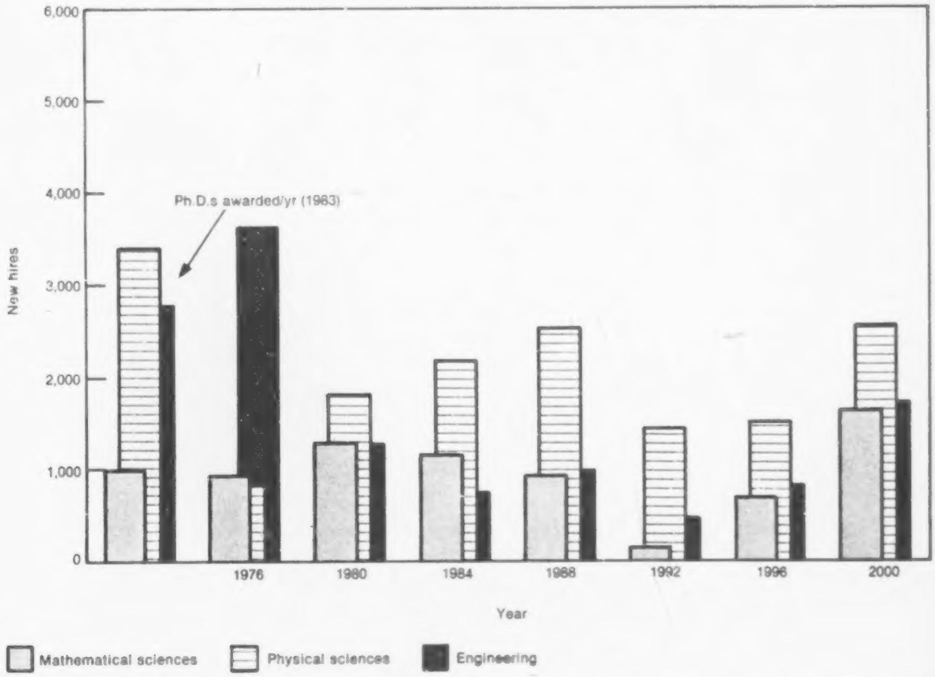
[8] National Research Council, *The Demand for New Faculty in Science and Engineering, 1979* (Washington, DC: National Academy of Sciences, 1980), pp. 62-63, 176-177.

Figure 3-4.—Annual New Hires by Field



SOURCE: National Research Council, *The Demand for New Faculty in Science and Engineering, 1979* (Washington, DC: National Academy Press, 1980), pp. 176 and 177.

Figure 3-5.—New Hires by Field



SOURCE: National Research Council, *The Demand for New Faculty in Science and Engineering, 1979* (Washington, DC: National Academy Press, 1980), pp. 176 and 177.

nately, that is a very difficult task, for two reasons. First, and most serious, is the extraordinary fact that *no organization*—not NSF, nor NRC, nor NCES—*actually measures the number of new faculty appointed in a given year*. Thus we cannot compare projections with any directly observed data.[9]

Peter Syverson and Lorna Foster of NRC have attempted to *infer* hiring rates indirectly from NRC's biannual Survey of Doctoral Recipients (SDRs), a longitudinal study of the career patterns of a 10-percent sample of science, engineering, and humanities Ph.D.s. Comparing responses to the 1981 and 1983 SDRs, Syverson and Foster estimate the growth in the number of faculty positions as "the change in the number of academically employed respondents between 1981 and 1983" and attrition as "the proportion of

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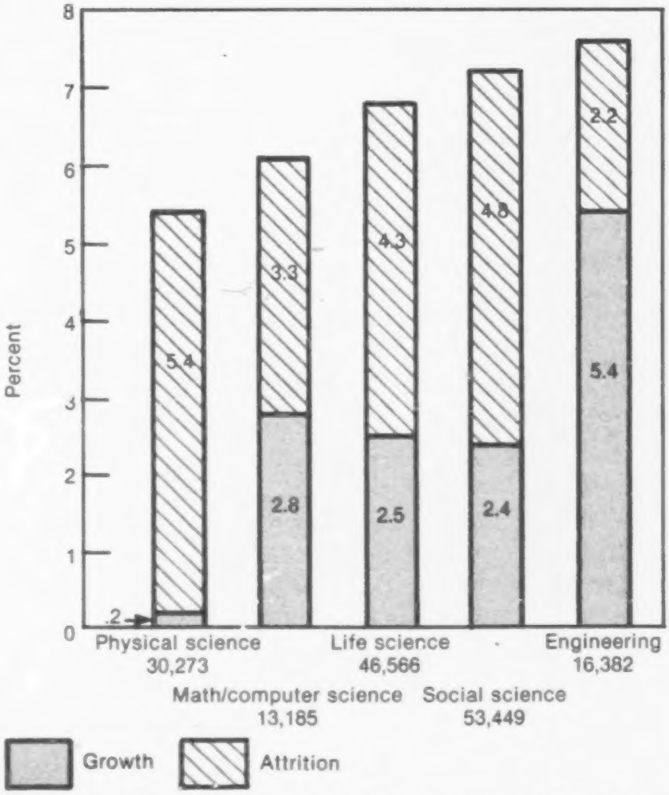
[9] In its most recent survey of Ph.D.-granting science and engineering departments the National Science Foundation asked chairmen to estimate the number of new full-time permanent appointments made in 1983. Unfortunately, this is a limited sample, and the results have not yet been published. Moreover, NSF has some reservations about the accuracy of reporting on this question. Personal communication from Christine Wise, Science Resource Studies Division, National Science Foundation, Sept. 23, 1985.

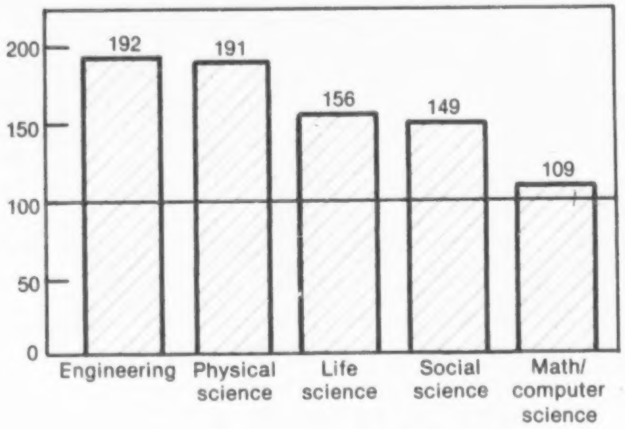
Figure 3-6.—Replacement Demand As a Percentage of the Total Academically Employed—Science and Engineering, 1983



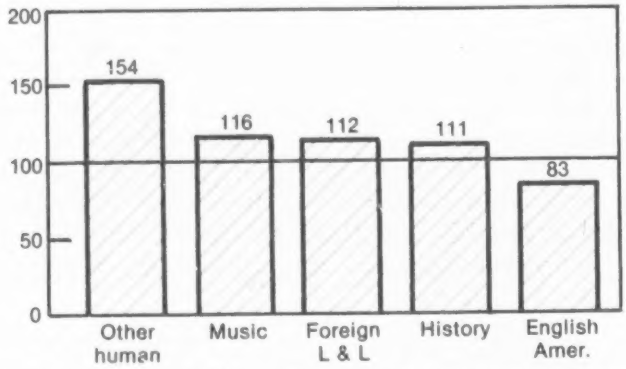
SOURCE: Peter Syverson and Lorna Foster, *New Ph.D.s and the Academic Labor Market* (Washington, DC: National Research Council, 1984), pp. 4 and 7.

Figure 3-7.—New Ph.D.s Per 100 Academic Job Openings

Science and Engineering, 1983



Humanities, 1983



SOURCE: Peter Syverson and Lorna Foster, *New Ph.D.s and the Academic Labor Market* (Washington, DC: National Research Council, 1984), pp. 4 and 7.

respondents who no longer reported academic employment" in 1983.[10] Syverson and Foster find that "even when the academic labor market is in an overall steady state, as it now appears to be, there continues to be demand on the order of 5 to 7 percent" for both replacement and growth. See figure 3-6 for the percentages by field. Comparing annual doctoral degree production for 1983 with the calculated number of job openings they find ratios ranging from about 190 new Ph.D.s per 100 academic job openings in engineering and physical science to 109 per 100 in mathematics and computer science, with the life and social sciences directly in the middle.[11] (See figure 3-7.)

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[10] Peter Syverson and Lorna Foster, "New Ph.D.s and the Academic Labor Market," Office of Science and Engineering Personnel Staff Paper No. 1, typescript, p. 2.

[11] Ibid., pp. 3 and 10.

For individual fields we can compare Syverson and Foster's calculated new hires with Kuh and Radner's projected new hires for 1983. The results are displayed below:

New Academic Hires, by Science and Engineering Field, 1983

	Kuh-Rudner	Syverson	Syverson as % of K-R
Physical science	2,096	1,639	(78 percent)
Mathematical science	1,160	810	(70 percent)
Engineering	893	1,246	(150 percent)
Life sciences	4,348	3,179	(73 percent)
Social sciences	1,690	3,842	(227 percent)
Total	10,187	10,716	(105 percent)

Although the totals for science and engineering are reasonably close, there are clearly serious discrepancies between the projections and the calculated new hires in all fields, with the greatest differences appearing in the social sciences and engineering. The fact that some fields are substantially overprojected while others are underprojected indicates that the problem is probably not simply one of a lack of comparability in the populations being studied.

A second factor limiting the ability to treat projections from models such as that of Kuh and Radner as precise numerical predictions is the extreme sensitivity of those projections to assumptions made by the modellers about certain key parameters connecting enrollment to the demand for faculty. These parameters include retirement rates, tenure and promotion rates, voluntary "quit rates," and variations in the overall ratio of faculty to students from year to year. Robert Klitgaard reports that "reasonable variations" in one parameter alone, "quit rates," lead to projections of new hires differing by a factor of 5 or 6 by 1985.[12]

Lee Hansen and Karen Holden have calculated the effect of changing the mandatory retirement age from 65 to 70. They find that a 5-year shift in the retirement age assumed in their projection model causes a 63-percent drop in the projected number of new faculty hired in the 1987, and a 23-percent drop in projected new faculty hires in 1992.[13] For 1987, the number of projected new hires falls from 38.8 percent of its 1977 level to 14.5 percent, while for 1992 the projected percentage declines from 44.2 to 33.9 percent.

Klitgaard, in a provocative essay on the pitfalls of forecasting academic demand, shows the effects of changing assumptions about retirements, "quits," promotions, and faculty-student ratios. Taking a model developed by Louis Fernandez, Klitgaard simultaneously varies each of the above-mentioned parameters to the limit of its range of uncertainty and then adds or multiplies the variances produced. The result is depicted in figure 3-8 which shows a variation of a factor of 6 between the sum (or product) of

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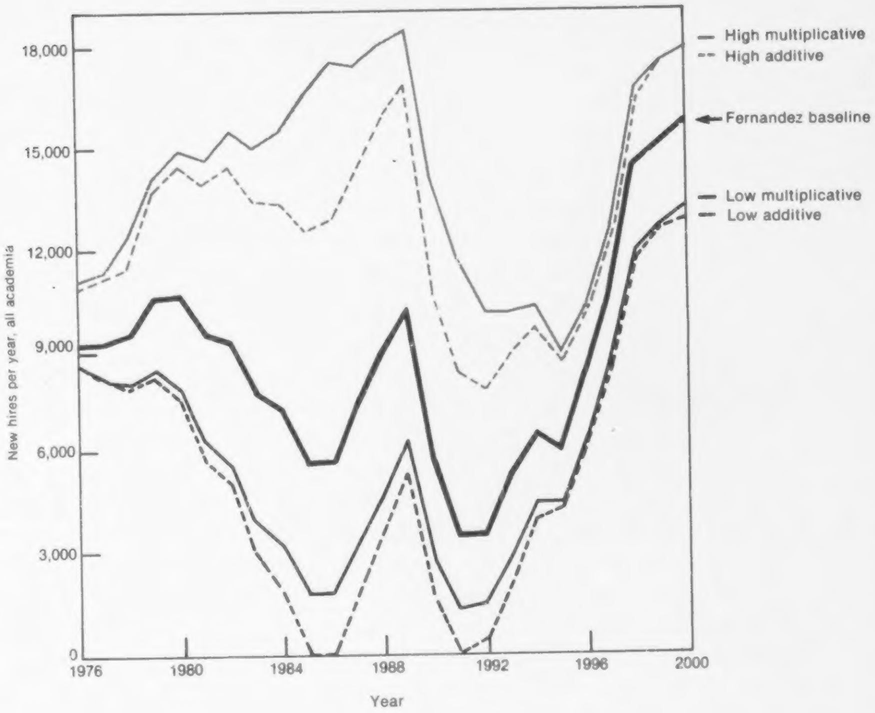
[12] Robert E. Klitgaard, *The Decline of the Best?* Discussion Paper No. 65 D (Cambridge, MA: John F. Kennedy School of Government, Harvard University, May 1979), p. 16.

[13] W. Lee Hansen and Karen C. Holden, "Critical Linkages in Higher Education: Age Composition and Labor Costs," *Insurance Mathematics & Economics*, vol. 4, No. 1, January 1985, pp. 60-61.

Figure 3-8.—Sensitivity of Hiring Projections to Variations in Input Parameters



NOTE: The variability represented here does *not* include uncertainty in enrollments. Calculations and graph by author.

NOTE: The variability represented here does *not* include uncertainty in enrollments. Calculations and graph by author.

SOURCE: Robert E. Klitgaard, *The Decline of the Best?* Discussion Paper No. 65 D (Cambridge, MA: John F. Kennedy School of Government, Harvard University, May 1979), p. 19.

the extreme highs and the sum (or product) of the extreme lows of all of the variables taken together.[14]

In April 1985, at the request of OTA, NRC convened a panel of academic labor market specialists to determine whether the projections made in the late 1970s are still valid, in the light of new data and subsequent analyses. The panel devoted a great deal of attention to the many uncertainties that surround projections of student enrollments, faculty retirements, "quit rates," promotions, tenure decisions, and salaries. However, there was general agreement that the overall direction of change projected in the late 1970s was still valid. According to Michael McPherson, a participant at both the 1978 and 1985 NRC workshops:[15]

> One point that is very much worth underlining is that we all seem to be in rough agreement: the 1970s projections of overall demand for teachers for the next decade aren't obviously wrong. People knew there were uncertainties

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[14] Klitgaard, op. cit., p. 19.

[15] National Research Council, "Draft Proceedings of the Workshop on the Forecasting of Demand for University Scientists and Engineers," Apr. 8, 1985, pp. 32 and 49.

> when they were made; of course, uncertainties still exist, but if there is something really wrong with the projections, it is not anything that we have detected . . . .
>
> . . . . by and large, all people looking at this question generally have the same picture of what will occur. There is much agreement both about the major quantitative factors impinging on this set of labor markets and, at a broad level, about how the market will react to those forces.

There was also substantial agreement that despite the consensus on overall trends, the range of uncertainty in the factors that influence demand make any numerical comparisons with predicted supply very problematic. McPherson summarized these uncertainties as follows:[16]

> The workshop discussions . . . . highlighted a number of complications and qualifications, some of which were acknowledged in the earlier work. Among the most important of these were the following:

1. The *Research Excellence* study focused on the demand for teaching faculty, but research support generates academic hiring too, especially in major universities. Some universities are evolving elaborate patterns of nonfaculty research staffing, partly in response to anticipated declines in teaching positions. To the extent that universities can successfully decouple teaching from research hiring in this way, the effects of fluctuations in enrollment on research effectiveness may be mitigated.
2. *Research Excellence* and related studies treated the pace of retirements as mechanically determined by faculty demographics, whereas in fact retirement should be seen as a *decision* influenced by, among other things, the economic incentives facing retirees.
3. *Research Excellence* followed the modeling work of Radner and Kuh in supposing that universities would respond to declining demand for faculty by reducing the rates at which they promoted people to tenure . . . . So far that is apparently not happening: universities are hiring more faculty off the tenure track but continue to promote tenure-track faculty as before.
4. The models on which *Research Excellence* relied dealt with academia as a whole, but in fact different segments of the academic system may behave very differently in the years ahead.
5. It is similarly important to recognize that different fields within science and engineering are likely to fare very differently, owing both to variations in research funding and in student course preferences.

Because of these uncertainties, participants at the workshop generally felt that it is more important to analyze existing data and refine our understanding of how the academic labor market works than to make detailed projections of the numbers of Ph.D.s required or produced in specific fields. In the words of Stephen Dresch:[17]

> . . . [we need] to have some reasonably sustained work in this area . . . nobody systematically asks, "What data should be collected to answer interest-

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[16] Michael S. McPherson, "Numbers and Quality: Analyzing the Market for University Scientists and Engineers," National Research Council, *Forecasting of Demand for University Scientists and Engineers: Proceedings of a Workshop* (Washington, DC: National Academy Press, 1985), p. 1.

[17] National Research Council, "Draft Proceedings," op. cit., p. 29.

> ing questions?" Therefore, a lot of money used to collect data is, in fact, wasted because the data collected has fatal flaws: it tracks some flows in the system but doesn't permit tracking other flows, a situation that could very easily have been rectified if one had been striving for a complete picture. A lot of data, in fact, is incomplete and can't be spliced together. The other side is that, for all practical purposes, we really don't want to pay anyone to learn anything with these data. What we essentially want is to "buy" the aura of rationality in action . . .

McPherson summarized the situation as follows:[18]

> On the qualitative side, we really need to understand better how this system behaves, recognizing that institutions and individuals adjust when conditions change. The simplest kinds of manpower forecasting models assume a great deal of rigidity—that people in institutions just continue to do what they used to do in the face of radical changes in conditions—but we know that is false, because in one way or another gaps get filled . . . . It is in the adjustment process that better qualitative understanding is needed. For that purpose the quantitative models are not really so much intended to be accurate predictions of the future as guidelines that show us where the adjustments will have to occur and direct our understanding.
>
> Now, to achieve this qualitative understanding, we don't really want to develop a super-elaborate, sophisticated structural model . . . . Instead, we should study the many variables—wage behavior, tenure policies and how they respond, how universities handle nonfaculty research positions—and build up from that a better understanding, not so much to predict but to understand how this beast operates. What we need is more basic research into these labor markets.

Participants at the workshop listed the following items for research on the qualitative aspects of the academic labor market:[19]

1. How is the *quality* of students attracted to advanced study influenced by changes in labor market conditions? Will declining demand cause the best students differentially to select themselves out of scientific careers?
2. How do academic departments cope with hiring shortages like those now being experienced in engineering, and with what implications for research and teaching effectiveness?
3. How, and how effectively, do universities respond to reductions in demand for teaching faculty?
4. What factors influence the mobility of experienced Ph.D.s, both among fields and between academic and nonacademic employment?

Peter Syverson of NRC summarizes the state of the art of forecasting supply and demand in the academic market as follows:[20]

> At present our ability to forecast changes in the academic market is decidedly limited. For anything more refined than seat-of-the-pants planning, a far more precise model must be developed to accurately reflect the academic market up to and beyond the turn of the century.

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[18] Ibid., p. 51.

[19] McPherson, op. cit., p. 4.

[20] Syverson, op. cit., p. 12.

IMPLICATIONS OF THE TRENDS

The implications of the overall trends projected by labor market specialists in the late 1970s, and confirmed by the NRC workshop in April 1985, were discussed at great length in conjunction with the early forecast of a declining academic labor market for Ph.D.s in the 1980s and early 1990s. Kuh and Radner, for example, in their work on *Preserving a Lost Generation* argued that:[21]

> It is in both the national interest and the interest of individual institutions to assure a moderate but steady flow of young doctorate scholars into academia . . . . An academic enterprise in which half as many young faculty did twice as much teaching could not help but result in a considerably smaller amount of research, with considerable consequence for U.S. science . . . . When fewer and fewer people can be hired, the predictors (of creative and lasting scholarship) are likely to become more and more conservative. The young Ph.D. who has two published articles in addition to his thesis is likely to be chosen over the young Ph.D. who has an interesting area of research with a longer gestation period. "Mistakes," after all, are much more costly when they can be spread over fewer people. But, in fact, the research with the longer gestation period may be more productive in the long run . . . . Programs are needed which allow [the research universities] to take some "long shots" in the hiring of young scholars. The larger the pool, the more likely that the best scholars will be found in it.

The 1979 National Academy of Sciences report on *Research Excellence Through the Year 2000: The Importance of Maintaining a Flow of New Faculty Into Academic Research,* cited above, enumerated in some detail the possible consequences for science of the projected decline in academic hiring of Ph.D.s. According to the Committee, "damage to the nation's research effort is likely to result from the expected constriction in the flow of new faculty" for a number of reasons:[22]

1. the rate of research innovation, the inflow of new ideas, and the vitality of the research environment will be impaired;
2. continuity in the education and socialization of succeeding generations of researchers will be threatened; and
3. the perceived lack of opportunities for an academic career may discourage able and creative young people from pursuing careers in basic scientific research.

The Carnegie Council on Policy Studies in Higher Education discussed the "implication of the demographic depression for faculty" in its 1980 report on the future of higher education:[23]

> The tenured professoriate in 4-year colleges will keep on aging with the ages of the modal group rising from 36 to 45 in 1980 to 56 to 65 in 2000. This will increase the age gap between students and faculty, raise the average cost of faculty salaries, and make it hard to introduce new fields, new courses, new subject matter. Tenure ratios, which were 50 percent as recently as 1969, have

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[21] Kuh and Radner, op. cit., pp. 2-3.

[22] National Research Council, *Research Excellence,* op. cit., p. vi.

[23] *Three Thousand Futures: The Next Twenty Years for Higher Education* (San Francisco, CA: Jossey Bass, 1980), pp. 80-82.

> now risen to 75 percent; and colleges encounter new rigidities in redeploying their resources.
>
> Some faculty members are potentially much more affected than are others: In the East and North more than in the South and West; in comprehensive colleges more than in community colleges; in less selective more than in more selective 4-year liberal arts colleges; in doctorate granting universities more than in research universities.

The response to these cries of alarm from distinguished educators and analysts is summarized in a review of the current state of the academic labor market in late 1984 by Michael McPherson. He finds that, to a remarkable degree, "the policy issues identified in the late 1970s and early 1980s" relative to the declining academic market for Ph.D.s "remain central and largely unresolved today."[24]

THE FURTHER FUTURE

All of the studies of the late 1970s ended their projections at the year 2000. Unfortunately that is just the beginning of a pronounced "rebound" period, when enrollments are expected to increase and large numbers of faculty hired in the 1960s and early 1970s are expected to retire. McPherson expresses the conventional wisdom when he states that "to the degree that student and faculty demographics are determining factors, data available now suggest that recovery will come quite late in this century and will not be strong."[25] However, projections for the first decade of the 21st century make the transition to growth appear considerably less smooth than McPherson argues. To examine the "rebound" in greater depth, OTA performed its own analysis of the period 2000-10, using the model developed by Herring and Sanderson for the 1981 *Report of the President of Princeton University* cited above. OTA first extended the Princeton model to the year 2015, using the same values for the input parameters as Herring and Sanderson, and population trends for 2000 to 2015 from the Census Bureau Projections of the Population, middle series, cited in chapter 2. The results, displayed as the white bars on figure 3-9, show a tripling in demand for new faculty, from 6,500 per year between 1980 and 1995 to 20,000 per year between 1995 and 2010.

OTA then revised the Princeton model to incorporate a different set of assumptions about resignations and retirements, which OTA believes track recent data on these two phenomena more closely than those of Herring and Sanderson. The results are displayed as the striped bars on figure 3-9. As can be seen, the OTA assumptions lead to a level of new faculty hiring in the 1980-95 time frame that is nearly double that of Herring and Sanderson—12,000 per year. In the first decade of the 21st century, if the assumptions in the OTA simulation hold, the number of new academic hires per year could reach 25,000 per year, or double that of the early 1990s.

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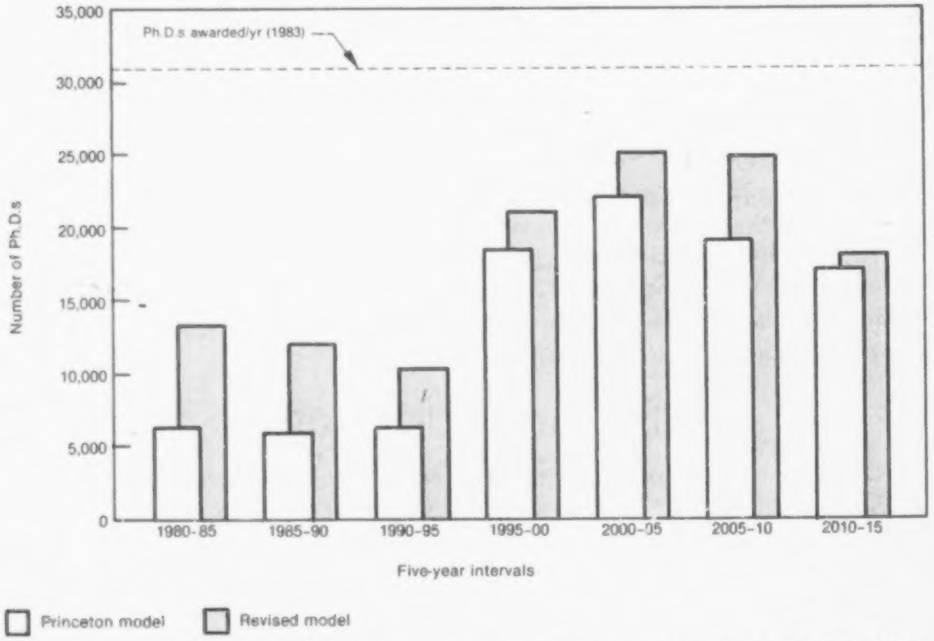
[24] Michael S. McPherson, "The State of Academic Labor Markets," November 1984 draft, p. 5, to be published in B.L.R. Smith (ed.), *The State of Graduate Education* (Washington, DC: The Brookings Institution, 1985).

[25] Ibid., p. 29.

Figure 3-9.—Annual Number of New Hires Based on Projections



SOURCES: William G. Bowen, *Report of the President* (Princeton, NJ: Princeton University, April 1981); and Office of Technology Assessment analysis.

Hansen and Holden project that new faculty hires could increase by a factor of 4 between 1987 levels and 2002. In their worst case scenario, in which most faculty choose to retire at age 70, the increase between 1987 and 2002 would be a factor of 10.[26]

The implications of this dramatic reversal of fortunes for universities and new science and engineering Ph.D.s have not been examined to date. Although it appears that the academic demand for new faculty will remain below the annual supply of new Ph.D.s, even in the boom years 2000 to 2010, that situation could, in fact, change dramatically if graduate school enrollments drop sharply in the 1990s due to the weak market for new faculty in that time period. In other words, if graduate students respond to the market signals of the early 1990s by decreasing their enrollments in doctoral programs, there could be too few of them to meet the surging demand that will occur at the turn of the century. To avoid this potential market failure, it would be prudent to monitor new academic hires and, if the trends discussed above materialize, possibly institute countercyclical support programs in the early 1990s.

Even if the supply of new Ph.D.s increases to meet demand in the early 21st century, a countercyclical policy for the early 1990s may be worth considering for a second reason. The large number of new faculty hired in the 1995-2010 time period will produce an age distribution among faculty in

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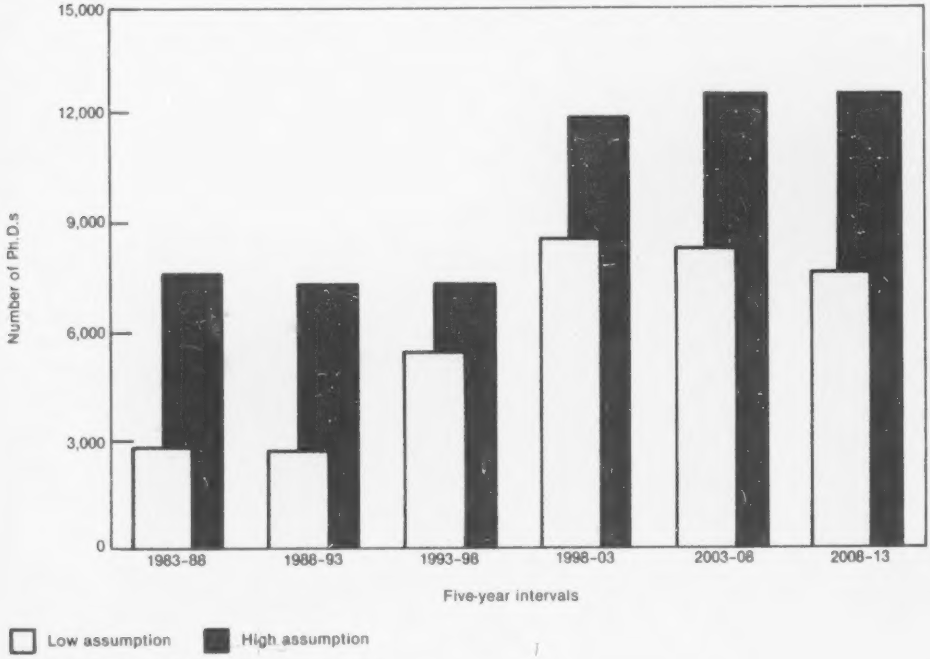
[26] Hansen and Holden, op. cit., p. 60.

Figure 3-10.—Annual Hiring, Science and Engineering Faculty, Extreme Cases



SOURCE: Office of Technology Assessment.

the second decade of the 21st century that is heavily skewed toward the young, as was the age distribution in the late 1970s. (See figure 3-1, above.) This could lead to a repeat of the low retirement, low replacement situation of the 1980-95 time period. To avoid a repetition of the "boom and bust" cycle of the 1960s and late 1970s it may be worthwhile to attempt to formulate a countercyclical policy to stimulate demand in the early 1990s.

The science and engineering fields appear to follow the general academic market fairly closely. OTA applied a revised version of the Princeton model to the most recent data from NSF on the age distribution of doctoral scientists and engineers employed at 4-year colleges and universities.[27] Using 1983 as a base year, OTA was able to project the number of new junior faculty appointments that would be made at 5-year intervals from 1983 to 2013, under different assumptions about retirements, resignations, and enrollments in science and engineering courses. Figure 3-10 shows the variation in the demand for new science and engineering faculty over the 30-year period under two extreme assumptions: one of high demand for science and engineering faculty, high rates of retirement among senior faculty, and high rates of resignation among junior faculty; and one of low demand, low retirements, and low resignations. These appear to represent reasonable estimates of the extreme levels of possible academic hiring of new science and engineering Ph.D.s over the next three decades.

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[27] *Characteristics of Doctoral Scientists and Engineers in the United States: 1983*, NSF 85-303 (Washington, DC: National Science Foundation, 1985), table B-5, pp. 19-23.

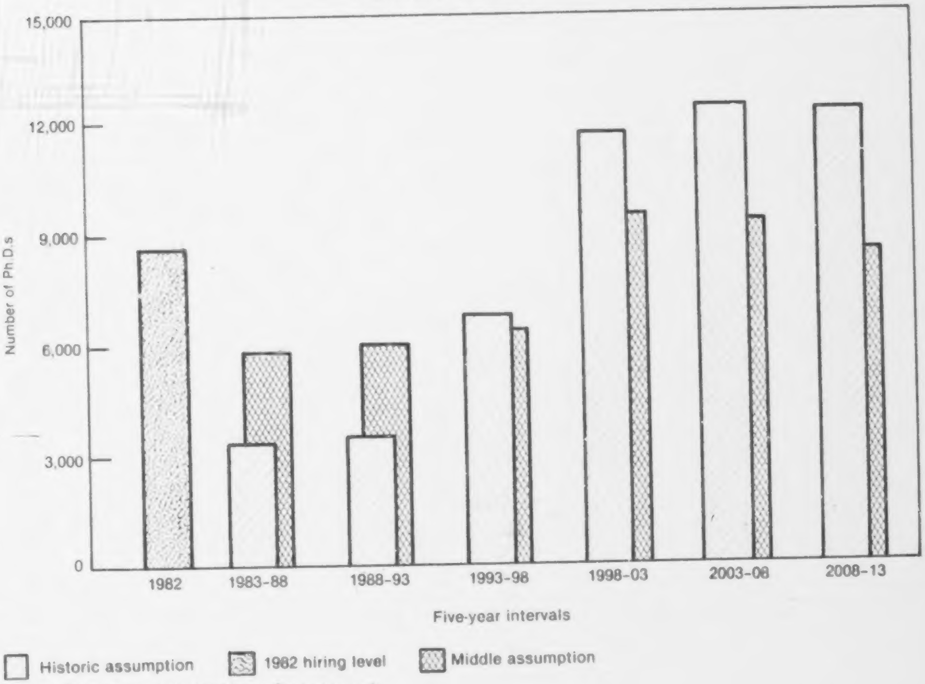

Figure 3-11.—Annual Hiring, Science and Engineering Faculty, Middle Cases

SOURCE: Office of Technology Assessment.

To refine its analysis, OTA applied its model to historical data on Ph.D. scientists and engineers in educational institutions for the years 1973 to 1983 published by NSF.[28] OTA found that a high demand, low retirement, low resignation scenario best fit historic data. Two versions of such a scenario are displayed in figure 3-11 which represents an educated guess based on historical experience as to the likely range of academic hiring of science and engineering Ph.D.s over the next 30 years. The number of science and engineering doctorates appointed by colleges and universities in the 1977-82 time frame, as calculated by OTA from NSF data, is also displayed in figure 3-11 as an average number of new hires per year over the 5-year period. As can be seen, the number of new scientists and engineers appointed by colleges and universities declines significantly in the 1983-98 time frame. It then increases to more than 9,000 per year in the 1998-2013 time frame. Similar projections for individual fields follow similar patterns, as can be seen from figures 3-12, 3-13, and 3-14 which show the hiring trends for the physical sciences, the life sciences, and the social sciences under the two scenarios most consistent with past experience.

INDUSTRIAL EMPLOYMENT OF SCIENCE AND ENGINEERING PH.D.s

The trends discussed above in the academic employment of science and engineering Ph.D.s must be placed in the context of the availability of alter-

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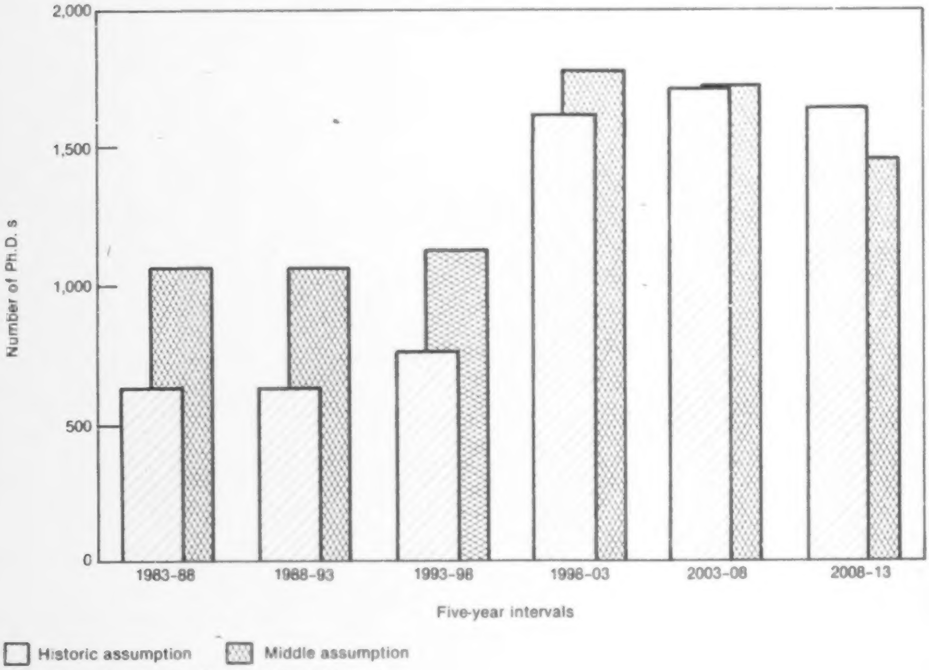
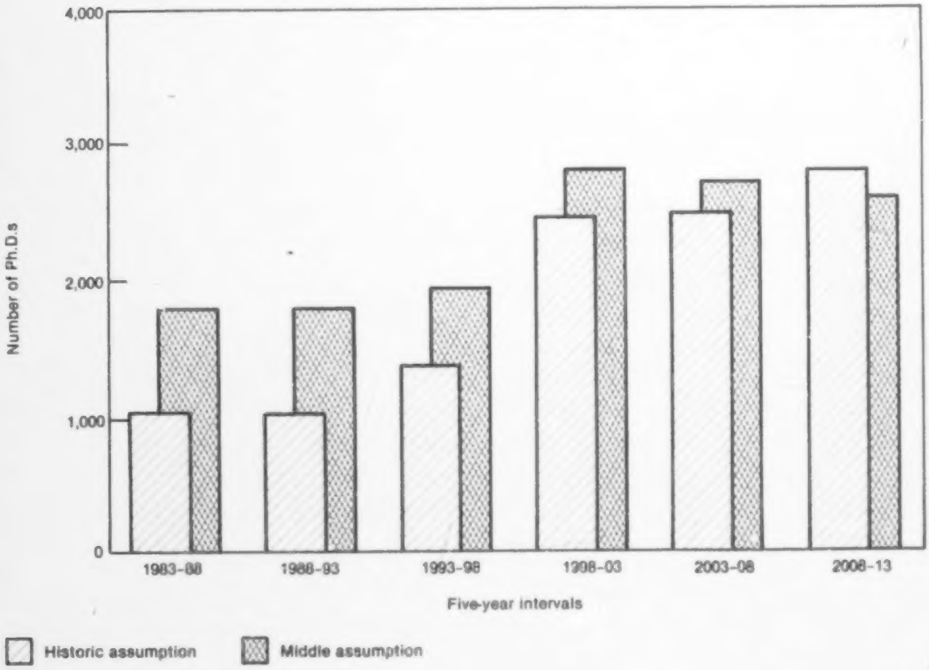
[28] Ibid., table 3, pp. x and xi.

Figure 3-12.—Projected Annual Hiring: Physical Scientists



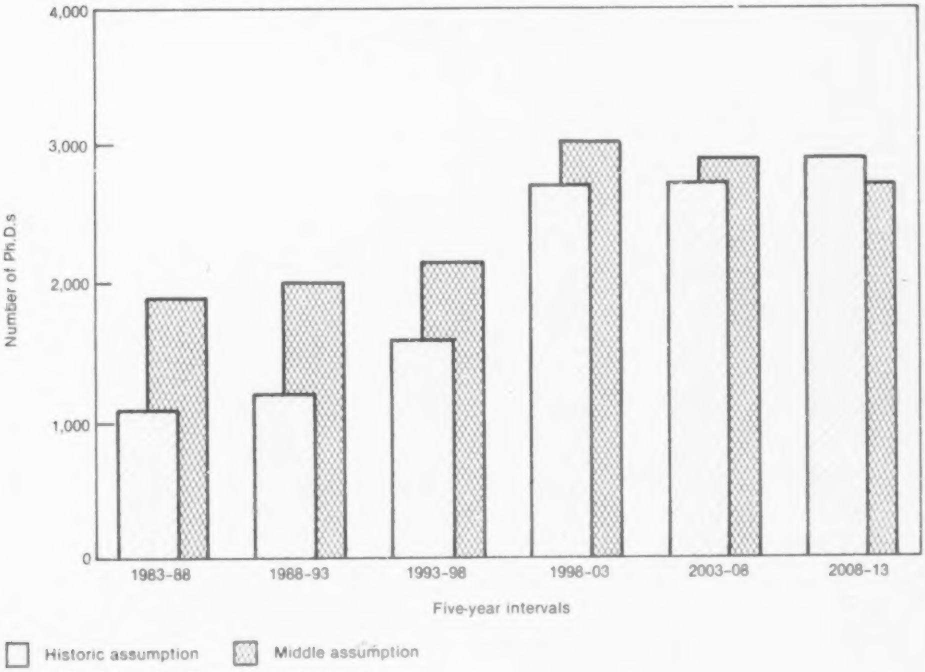
SOURCE: Office of Technology Assessment.

Figure 3-13.—Projected Annual Hiring: Life Scientists



SOURCE: Office of Technology Assessment.

Figure 3-14.—Projected Annual Hiring: Social Scientists



SOURCE: Office of Technology Assessment.

native careers for those professionals. As tables 3-1 and 3-2 show, educational institutions employ only 52 percent of all Ph.D. scientists and engineers, and less than 48 percent of those who received their doctorate after 1977. The variation from field to field is substantial, with mathematics, social science, and biology having two-thirds or more of their Ph.D.s employed in academia, while chemistry and engineering are at one-third or less academic employment. By comparison, in the humanities 83 percent of all Ph.D.s are employed at educational institutions.[29] Of course, the principal alternative market for science and engineering Ph.D.s is industry, which has increased its share of the employed doctorates in those fields by 10 percent in recent years. In physics, chemistry, and biology the industrial share of employed doctoral scientists is 20 percent higher among recent Ph.D.s than it is in the overall population of doctoral degree holders.

The increasing share of science and engineering Ph.D.s employed in industry is an important phenomenon that deserves closer scrutiny. In 1973, there were 53,400 Ph.D. scientists and engineers employed in industry, as compared to 129,300 in academia, according to the National Science Foundation.[30] By 1983 the number of industrial scientists and engineers had more than doubled, to 113,500, while the number in academia had increased by only 50 percent, to 196,100. The rate of growth in industry was about 8

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[29] National Research Council, *Science, Engineering and Humanities Doctorates in the U.S.: 1983 Profile* (Washington, DC: National Academy Press, 1983), pp. 36, 37, and 74.

[30] *Science and Engineering Personnel: A National Overview*, NSF 85-302 (Washington, DC: National Science Foundation, 1985), table B-12a, p. 113.

Table 3-1.—Type of Employer of Doctoral Scientists and Engineers (1940-82 Graduates) by Field of Ph.D., 1983 (in percent)

	Field of doctorate											
Type of employer	All fields	Mathematics	Computer science	Physics/ astronomy	Chemistry	Earth/ environment	Engineering	Agriculture	Medicine	Biology	Psychology	Social science
Employed population[a]	350,900	18,500	2,500	28,100	44,900	12,000	55,000	16,900	12,900	57,600	47,500	55,000
Educational institutions	52.2	73.0	46.5	47.5	32.6	45.4	34.9	57.8	56.5	64.1	47.1	71.8
Business/industry[b]	31.7	19.2	47.7	36.3	57.3	30.0	54.2	22.4	24.2	18.0	27.5	12.8
U.S. Government	7.6	5.1	4.2	10.8	5.8	17.9	7.1	14.0	7.3	8.7	3.7	7.2
State/local government	2.0	0.2	0.1	0.3	0.7	3.3	0.6	2.5	2.8	2.1	4.7	3.0
Hospital/clinic	2.8	0.3	—	0.9	0.9	0.1	0.2	0.2	5.8	3.2	12.7	0.4
Other nonprofit organization	3.1	1.8	1.4	4.1	2.2	2.9	2.6	2.2	3.1	3.6	4.1	3.3
Other	0.3	—	—	—	—	0.1	0.1	0.5	0.1	0.2	—	1.3
No report	0.2	0.4	0.1	0.2	0.3	0.4	0.2	0.4	0.4	0.2	0.2	0.2

[a] Includes full- and part-time employed only

[b] Includes self-employed.

SOURCE: National Research Council, *1983 Profile*, pp. 36, 37.

Table 3-2. —Type of Employer of Doctoral Scientists and Engineers (1977-82 Graduates) by Field of Ph.D., 1983 (in percent)

	Field of doctorate											
Type of employer	All fields	Mathematics	Computer science	Physics/ astronomy	Chemistry	Earth/ environment	Engineering	Agriculture	Medicine	Biology	Psychology	Social science
Employed population[a]	80,800	3,600	1,200	4,300	7,000	3,000	11,500	3,800	3,800	11,100	15,900	15,600
Educational institutions	47.8	70.7	51.8	35.7	18.4	42.8	32.1	55.7	55.3	59.2	42.3	64.8
Business/industry[b]	34.1	21.6	44.3	44.0	73.6	35.3	57.2	29.1	23.2	22.8	27.2	17.1
U.S. Government	6.6	5.8	3.0	13.2	3.8	14.8	5.8	8.6	7.8	7.7	3.2	7.8
State/local government	3.1	0.1	—	—	0.9	3.5	1.0	2.3	2.2	2.7	6.1	4.9
Hospital/clinic	4.3	0.8	—	0.9	1.1	—	0.5	—	7.3	3.0	16.4	0.6
Other nonprofit organization	3.7	1.1	0.9	5.7	2.2	3.0	3.4	2.5	3.7	4.5	4.4	4.3
Other	0.1	—	—	—	—	0.4	—	0.9	—	—	—	0.4
No report	0.2	—	—	0.6	—	0.2	—	0.9	0.4	0.2	0.4	0.2

[a] Includes full- and part-time employed only.

[b] Includes self-employed.

SOURCE: National Research Council, *1983 Profile*, pp. 36, 37.

percent per year over the decade while that of academia was more like 4 percent per year.

Among the different science and engineering fields, computer scientists, psychologists, and social scientists showed the most dramatic growth in industry between 1973 and 1983, increasing by 300 to 500 percent (see table 3-3).[31] Of course, all three fields started from very low levels in 1973—3,000 or less. Engineering and physical science continued to employ the largest numbers of doctoral scientists and engineers—34,500 and 29,000 respectively in 1983—but their growth rates over the decade were lowest, at 100 and 46 percent respectively. The number of industrial Ph.D. scientists and engineers whose primary work activity was research and development doubled over the decade, but the numbers in consulting, sales and professional services, and "other" all quadrupled or quintupled. Fifty percent of the growth over the decade was in these three non-R&D related activities.

Even more dramatic, however, was the change in the relative demand for *new* Ph.D. scientists and engineers between industry and academia. Between 1973 and 1975 the number of academic Ph.D. scientists and engineers increased by 19,700, while the number of industrial Ph.D. scientists and engineers increased by only 11,200. Between 1981 and 1983, by contrast, the corresponding increases were 9,000 for academia and 14,300 for industry.[32] Thus the demand for *additional* science and engineering Ph.D.s in industry increased from 55 percent of the academic demand in the early 1970s, to 160 percent of the academic demand by the early 1980s.

To get a complete picture of the academic and industrial markets for science and engineering Ph.D.s we would need to add the *replacement* demand to the growth demands calculated above. The replacement demand in academia can be easily calculated with the OTA model described above, and it comes to 8,000 additional science and engineering Ph.D.s needed in 1981 to 1983. There is no data on the replacement rate for industrial Ph.D. scientists and engineers, but if we assume it to be equal to that of academia, or about 2 percent per year, that would generate demand for an additional 4,000 of those professionals between 1981 and 1983. The total industrial demand for new Ph.D. scientists and engineers would about 18,000 between 1981 and 1983, while the academic demand was 17,000.

There is evidence, however, that the industrial demand for new doctoral scientists and engineers is not wholly supplied by recent Ph.D.s. Based on a comparison of NSF[33] and NRC[34] data for the 1977-83 time period, it appears that only two-thirds of the additional industrial science and engineering Ph.D.s reported between 1977 and 1983 came from the pool of recent graduates. The rest were undoubtedly experienced Ph.D.s coming from academia and the government, and immigrants.

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[31] *Characteristics of Doctoral Scientists and Engineers in the United States: 1983*, op. cit., table 4, p. xii-xiii.

[32] Ibid., tables 3 and 4, pp. x-xiii.

[33] *Science and Engineering Personnel: A National Overview*, op. cit., table B-12a, p. 113.

[34] National Research Council, *Science, Engineering, and Humanities Doctorates in the United States: 1983 Profile*, op. cit., table 2-8, p. 37.

Table 3-3.—Selected Characteristics of Doctoral Scientists in Business and Industry

	1973				1983			
Characteristics	Number	Percent	Percent of total employed	Median annual salary	Number	Percent	Percent of total employed	Median annual salary
Total	53,403	100.0	24.2	23,300	113,463	100.0	30.7	47,000
Field:								
Scientists	35,631	66.7	19.3	23,300	76,963	69.6	25.7	45,500
Physical scientists	19,665	36.8	40.5	22,700	28,748	25.3	44.9	45,900
Chemists	15,759	29.5	51.2	22,500	22,525	19.9	54.5	45,600
Physicists/astronomers	3,906	7.3	22.0	23,600	6,223	5.5	27.4	48,300
Mathematical scientists	864	1.6	7.1	24,100	2,027	1.8	12.4	42,700
Mathematicians	657	1.2	6.2	23,900	1,512	1.3	11.1	43,600
Statisticians	207	0.4	14.1	25,100	515	0.5	18.5	40,000
Computer/information specialists	1,007	1.9	37.1	22,300	6,819	6.0	56.1	42,700
Environmental scientists	2,204	4.1	21.4	22,600	5,154	4.5	31.3	48,500
Earth scientists	2,085	3.9	24.4	22,500	4,596	4.1	36.7	49,200
Oceanographers	94	0.2	8.3	(a)	217	0.2	12.5	(a)
Atmospheric scientists	25	(b)	3.9	(a)	341	0.3	15.5	48,600
Life scientists	7,147	13.4	12.6	23,300	16,444	14.5	17.7	43,700
Biological scientists	3,309	6.2	9.0	22,800	7,730	6.8	14.0	41,800
Agricultural scientists	1,718	3.2	18.7	21,600	3,583	3.2	24.6	40,100
Medical scientists	2,120	4.0	19.9	26,300	5,131	4.5	22.2	50,700
Psychologists	3,081	5.8	12.4	30,000	13,020	11.5	27.9	48,000
Social scientists	1,663	3.1	5.7	27,200	6,751	5.9	11.4	45,400
Economists	1,031	1.9	10.7	29,200	2,779	2.4	16.4	52,100
Sociologists/anthropologists	125	0.2	1.9	(a)	801	0.7	6.6	36,300
Other social scientists	507	0.9	3.8	25,200	3,171	2.8	10.5	35,600
Engineers	17,772	33.3	49.7	23,200	34,500	30.4	56.1	49,900
Aeronautical/astronautical engineers	639	1.2	38.3	25,300	1,928	1.7	52.3	47,700
Chemical engineers	3,246	6.1	72.8	22,700	4,788	4.2	68.5	52,400
Civil engineers	883	1.7	28.5	21,500	1,895	1.7	35.6	47,600
Electrical/electronic engineers	3,424	6.4	48.5	23,600	7,615	6.7	60.0	51,200
Mechanical engineers	1,366	2.6	41.9	22,300	2,596	2.3	45.9	48,100
Nuclear engineers	666	1.2	52.7	23,100	1,380	1.2	59.3	46,200
Other engineers	7,548	14.1	50.4	23,600	14,298	12.6	57.5	48,700
Sex:								
Men	52,040	97.4	25.6	23,300	103,272	91.0	32.2	47,900
Women	1,363	2.6	8.1	20,200	10,191	9.0	20.9	38,900
Race:								
White	48,926	91.6	24.2	23,600	97,673	86.1	29.7	48,000
Black	298	0.6	14.6	23,000	675	0.6	13.6	43,900
Asian/Pacific Islander	3,099	5.8	30.0	20,800	13,431	11.8	45.2	44,800
American Indian/Alaskan native	5	(b)	3.5	(a)	69	0.1	16.5	(a)
Other	31	0.1	15.8	(a)	76	0.1	37.6	(a)
No report	1,044	2.0	19.3	23,000	1,539	1.4	27.7	39,800
Ethnicity:								
Hispanic	264	0.5	16.8	21,200	1,497	1.3	27.9	47,200
Nonhispanic	16,859	31.6	20.2	24,200	97,974	86.3	30.9	47,200
No report	36,280	67.9	26.8	22,900	13,992	12.3	29.6	45,200
Age:								
Under 30	1,999	3.7	20.6	17,800	2,037	1.8	31.5	36,400
30-34	12,267	23.0	24.7	20,100	16,432	14.5	34.1	38,700
35-39	10,435	19.5	24.8	22,500	25,491	22.5	33.6	44,100
40-44	8,520	16.0	24.1	24,900	26,059	23.0	32.5	50,100
45-49	7.098	13.3	23.7	26,800	15,900	14.0	30.7	50,900

Table 3-3.—Selected Characteristics of Doctoral Scientists in Business and Industry

	1973				1983			
Characteristics	Number	Percent	Percent of total employed	Median annual salary	Number	Percent	Percent of total employed	Median annual salary
50-54	6,288	11.8	26.1	27,800	10,656	9.4	26.8	53,100
55-59	3,874	7.3	24.9	27,600	7,451	6.6	23.4	55,800
60-64	1,957	3.7	21.7	27,900	6,153	5.4	27.3	53,800
65 and over	932	1.7	19.1	25,800	3,218	2.8	26.5	60,300
No report	33	0.1	33.0	(a)	66	0.1	26.1	(a)
Type of employment:								
Science/engineering	49,398	92.5	23.9	23,100	98,407	86.7	30.1	46,700
Other/unknown field	4,005	7.5	28.5	25,700	15,056	13.3	35.9	50,400
Primary work activity:								
Research and development	23,758	44.5	33.2	21,300	46,525	41.0	37.3	43,600
Basic research	3,525	6.6	10.3	21,600	6,731	5.9	11.8	42,100
Applied research	13,212	24.7	46.0	21,300	23,463	20.7	49.5	44,100
Development/design	7,021	13.1	82.6	21,100	16,331	14.4	80.5	43,600
Management/ administration	19,840	37.2	43.0	27,000	25,528	22.5	41.3	55,900
Of R&D	14,242	26.7	54.3	26,300	20,066	17.7	63.9	55,600
Of other	5,598	10.5	28.1	29,400	5,462	4.8	18.0	60,000
Teaching	191	0.4	0.2	(a)	1,301	1.1	1.2	41,700
Consulting	2,781	5.2	68.6	25,100	10,673	9.4	83.7	48,300
Sales/professional services	3,001	5.6	37.2	25,400	15,581	13.7	52.3	48,400
Other	2,988	5.6	43.0	21,700	12,303	10.8	50.9	44,500
No report	844	1.6	22.9	23,200	1,552	1.4	20.0	50,000

[a] No median computed for groups with fewer than 20 individuals.

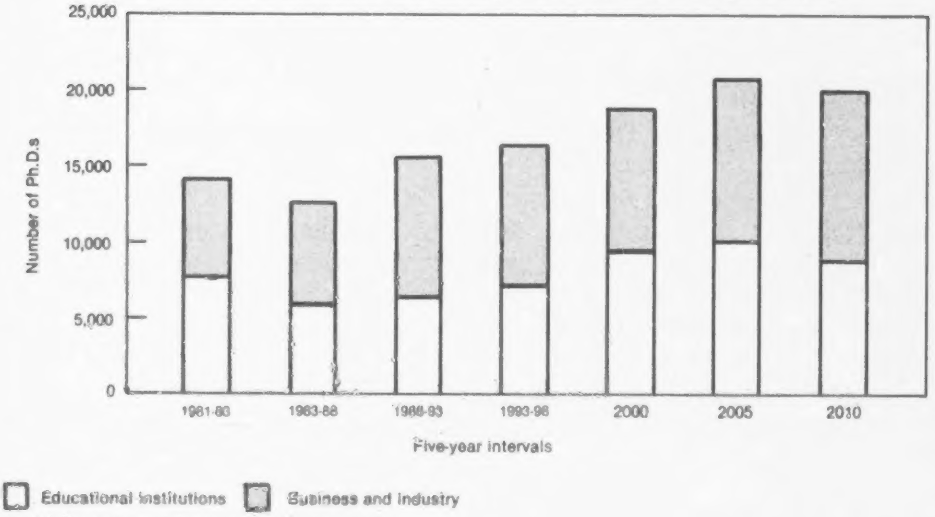
[b] Less than 0.05 percent.

NOTE: Percents may not add to 100 because of rounding.

SOURCE: *Characteristics of Doctoral Scientists and Engineers in the United States: 1983* (Washington, DC: National Science Foundation, 1985), pp. xii and xiii.

It is difficult to predict the future industrial market for science and engineering Ph.D.s with any degree of certainty in the absence of an understanding of the causes of the dramatic growth of the past decade. It is clear, however, that if the recent growth rate were to continue for another decade it would generate substantial employment opportunities for doctoral scientists and engineers. Assuming that the 7.8-percent growth rate experienced in the 1970s continues through the 1980s, and that new science and engineering Ph.D.s continue to account for two-thirds of that growth, as they did in 1977 to 1983, there would be about 7,000 new doctoral scientists and engineers hired by industry each year between 1983 and 1988, and 10,000 hired each year between 1988 and 1993. Both of those figures exceed the projected academic demand for those years by a considerable amount. When added to the projected academic demand for the two time periods, they lead to the combined demand for new science and engineering Ph.D.s in the two sectors between 1983 and 1993 shown in figure 3-15. As can be seen, the totals for 1983 to 1993 are quite close to that of the 1981-83 time period. Thus, the decline in academic hiring over the next decade could be completely compensated for by the increase in industrial demand.

Figure 3-15.—New Ph.D. Hiring: Science and Engineering



SOURCE: Office of Technology Assessment.

Beyond the next decade, predictions of industrial demand for Ph.D. scientists and engineers become even more speculative. The continuation of the 7.8-percent growth rate for more than another decade seems unlikely for two reasons. First, the numbers of new Ph.D. scientists and engineers required for 8 percent per year growth for another decade become so large they are impossible to believe (the industrial sector alone would require twice as many new Ph.D.s per year as all sectors required in 1983). Second, the surge in growth in industrial science and engineering Ph.D.s is a relatively recent phenomenon. Statistics published by NRC[35] show that the percent of new Ph.D.s planning employment in business and industry *declined* steadily for all the science fields through the 1960s, and only began to increase in 1973. "Until recently the trend has been downward for employment of new science Ph.D.s in business and industry" NRC wrote in 1978. "Is a change coming?" it wondered. If the trend reversed itself in 1973 it seems entirely possible it could change again in another decade.

The simplest assumption for the 1993-2003 time frame is that the rate of industrial hiring of new science and engineering Ph.D.s remains constant at its 1993 level. Using that assumption, the combined academic and industrial demand increases substantially above the 1983 level between 1993 and 1998 and grows to exceed the current annual supply of new science and engineering Ph.D.s between 1998 and 2003.

The American Institute of Physics (AIP) has recently completed an in-depth analysis of the long-term market for physics Ph.D.s that tends to support the analysis presented above. The AIP projects that the total industrial, government, and academic demand for new physics Ph.D.s could exceed the projected supply by the year 2000 under the most likely scenarios.[36] (See figure 3-16.)

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[35] National Research Council, *A Century of Doctorates* (Washington, DC: National Academy of Sciences, 1978), p. 81.

POSTDOCTORAL APPOINTMENTS

Among new science and engineering Ph.D.s who do not obtain a faculty position or enter industry, the principal alternative mode of employment is the postdoctoral appointment. The National Research Council defines a postdoctoral as a "temporary" appointment the primary purpose of which is to provide for continued education or experience in research usually, though not necessarily, under the supervision of a senior mentor.[37] NRC gives a number of rationales for the increasing percentage of Ph.D.s taking postdoctoral appointments:[38]

> In many areas of science and engineering, especially the interdisciplinary and transdisciplinary ones, the nature of research has become increasingly complex, and has required young investigators to develop highly specialized skills. Frequently these skills can be acquired more effectively through an intensive postdoctoral apprenticeship than through a graduate research assistantship . . . .
>
> From the perspective of the young investigator the postdoctoral appointment . . . provide[s] a unique opportunity to concentrate on a particular research problem without the burden of either the teaching or the administrative responsibilities usually given to a faculty member . . . . As the competition for research positions has intensified . . . . the opportunity as a postdoctoral to establish a strong record of research publications has become increasingly attractive to many young scientists interested in careers in academic research . . . .

However, there is now considerable evidence, and concern, that the postdoctoral appointment has become something of a holding pattern for new Ph.D.s who cannot find immediate faculty or industrial positions. A recent Higher Education Research Institute survey of doctoral degree holders who had taken postdoctoral appointments found that the number of respondents reporting "employment not available elsewhere" as the reason for taking a postdoc increased from 5.6 percent of the 1960 to 1967 graduates to 36.8 percent of the 1970 to 1973 graduates. The number citing "to become more employable" as a reason jumped from 19.4 percent in the former period to 39.0 percent in the latter.[39]

The number of science and engineering Ph.D.s with plans or firm commitments for postdoctoral study immediately following receipt of the degree has increased dramatically over the past quarter century. Figure 3-17 shows the "percent of Ph.D. recipients from U.S. universities planning postdoctoral study immediately after receiving the doctorate" between 1958 and

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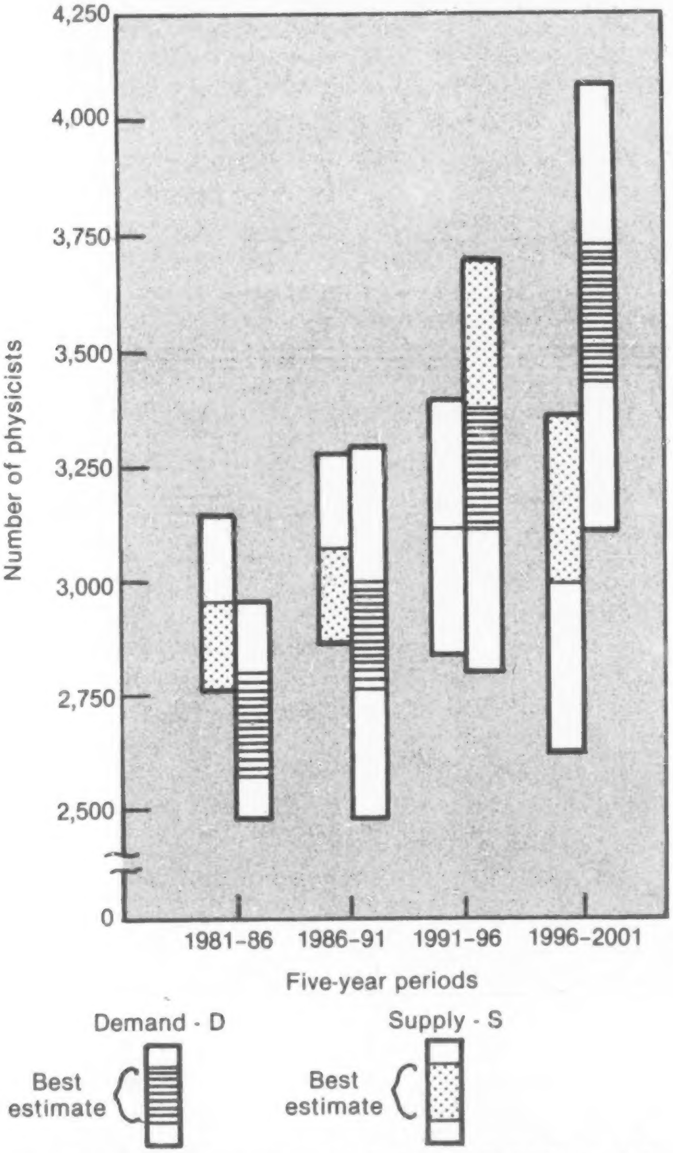
[36] U.S. Congress, House, "Testimony by Daniel Kleppner, Professor of Physics, Massachusetts Institute of Technology," Committee on Science and Technology, Task Force on Science Policy (Washington, DC: U.S. Government Printing Office, July 9, 1985), pp. 2-37.

[37] National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy Press, 1981), p. 11.

[38] Ibid., pp. 80-82.

[39] William Zumeta, "Anatomy of the Boom in Postdoctoral Appointments During the 1970s: Troubling Implications for Quality Science?" *Science, Technology and Human Values,* vol. 9, No. 2, spring 1984, pp. 23-37.

Figure 3-16.—Possible Levels of Supply and Demand for Physicists Within Each Five-Year Period, 1981-2001



SOURCE: American Institute of Physics, in Testimony by Daniel Kleppner to the House Committee on Science and Technology, July 9, 1985, p. 52-37

1982, by field.[40] It can be seen that in the biosciences, chemistry, physics, and astronomy the percent reporting postdoctoral plans has increased from approximately 10 percent in 1958 to between 40 and 60 percent in 1982. (It should be noted that data from 1958 to 1969 are not completely com-

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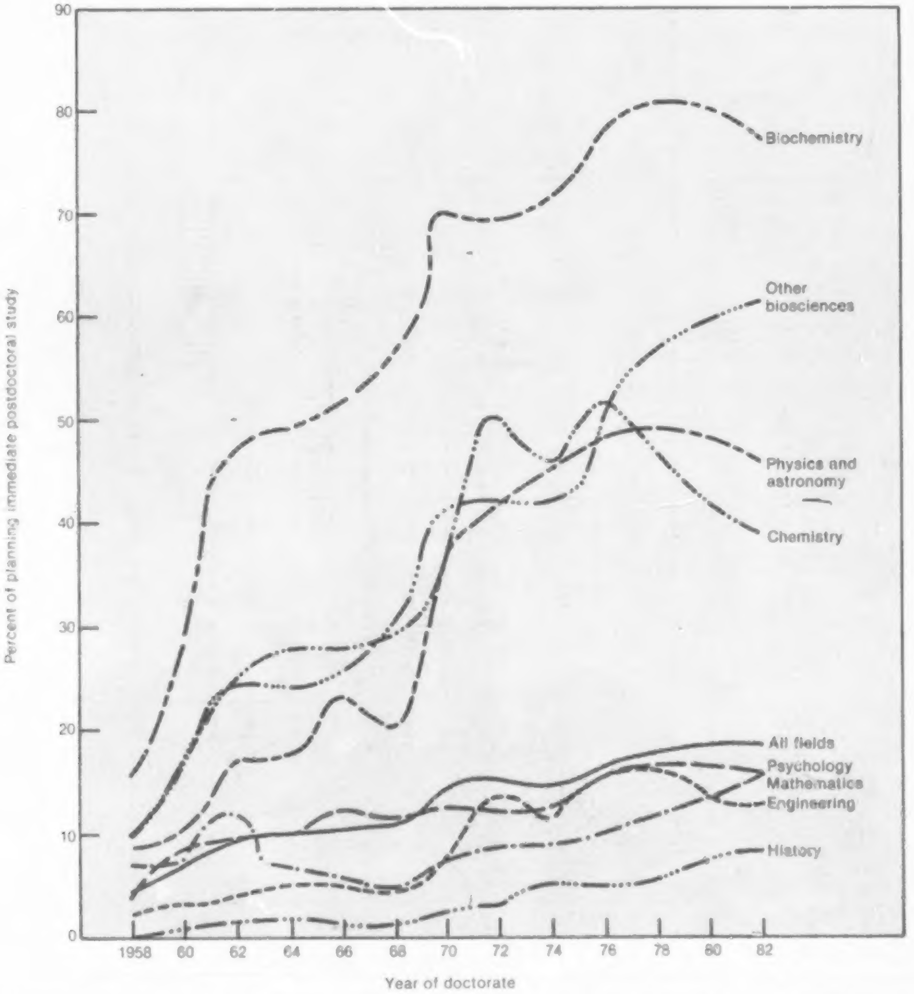
[40] William Zumeta, *Extending the Educational Ladder: The Changing Quality and Value of Postdoctoral Study* (Lexington, MA: D.C. Heath & Co., 1985), p. 7.

Figure 3-17.—Percent of Ph.D. Recipients From U.S. Universities Planning Postdoctoral Study Immediately After Receiving the Doctorate, Selected Disciplines, 1958-82



NOTE: Data were reported only for even-numbered years. Data for intervening years were interpolated.

SOURCE: William Zumeta, *Extending the Educational Ladder: The Changing Quality and Value of Postdoctoral Study* (Lexington, MA: D.C. Health & Co., 1985), p. 7.

parable to those from 1969 to 1983 because of a change in surveying procedures at NRC.) In biochemistry the percentage today exceeds 70 percent, while in most other science and engineering fields it is relatively low (10 to 20 percent).

According to NRC, postdoctoral appointees represented 3 percent of the U.S. doctoral scientific and engineering labor force of 365,000 in 1983, or 11,000 individuals.[41] This was an increase of 5 percent from the 10,500 reported by NRC for 1979.[42] More than 6,600 of the 1983 postdoctoral appointees, or 60 percent, were life scientists. They represented about 44 percent of the 15,000 Ph.D.s awarded in the life sciences in the 1981-83 period. (The average postdoctoral appointment lasts 3 years.) The next largest group, 2,200, or 20 percent, were in the physical sciences. They represented about 22 percent of the physical science Ph.D.s over the 1981-83 period. The social scientists at 1,200 were the third largest group. Engineers and mathematicians were far behind at 280 and 120 postdoctorals respectively.

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[41] National Research Council, *Science, Engineering and Humanities Doctorates in the U.S.: 1983 Profile,* op. cit., pp. 28-29.

[42] National Research Council, *Postdoctoral Appointments,* op. cit., p. 13.

Postdoctoral appointees with Ph.D.s from U.S. graduate schools—the population discussed above —represent only half of the total postdoctoral appointees in the United States. According to NSF[43] the total number of postdoctoral appointees in 1983, including those with foreign Ph.D.s and first professional degrees from U.S. schools, was 20,800, up 13 percent from a total of 18,500 in 1976.[44] Of these postdoctoral appointees, 15,000, or 73 percent, were supported by the Federal Government, with 10,000 or 50 percent on research grants. Since this chapter is concerned primarily with the fate of scientists and engineers who receive Ph.D.s from U.S. universities, the 11,000 postdoctoral appointees surveyed by NRC is the more relevant population.

In 1981 NRC completed a comprehensive study of "Postdoctorals in Science and Engineering in the United States," which examined in depth the role of the postdoctoral appointment in the transition from graduate school to the workplace.[45] It found that between 1973 and 1979, 29 percent of the science and engineering Ph.D.s who entered the labor force each year (4,300 out of 15,000) took postdoctoral appointments. In the biosciences, 55 percent of the new Ph.D.s who entered the labor force each year (2,000 out of 3,600) took an immediate postdoctoral appointment. In physics and chemistry, the fields with the next highest proportions of postdoctoral appointments, the corresponding percentages were 46 and 40 percent.

NRC also found that in the biosciences, the duration of the postdoctoral appointment had increased appreciably. Fifty-seven percent of the bioscientists who received their degree in 1976 and reported plans for postdoctoral study to NRC held appointments for longer than 2 years, up from 34 percent among 1969 doctoral degree recipients reporting planned postdoctoral study. Thirty-five percent of the 1975 Ph.D. recipients reporting planned postdoctoral study, as opposed to 12 percent of the 1968 recipients with similar plans held appointments for more than 3 years.[46] (See figure 3-18.)

To determine the effect of the postdoctoral appointment on future employment prospects, NRC compared the 1979 employment situation of a sample of bioscience physics, and chemistry Ph.D.s who received their degree in 1972 and took a postdoctoral appointment immediately thereafter, with the situation of a comparable sample of Ph.D.s from the same fields and year who never held such an appointment. It found that the group that had taken postdoctoral appointments was far more likely to be employed

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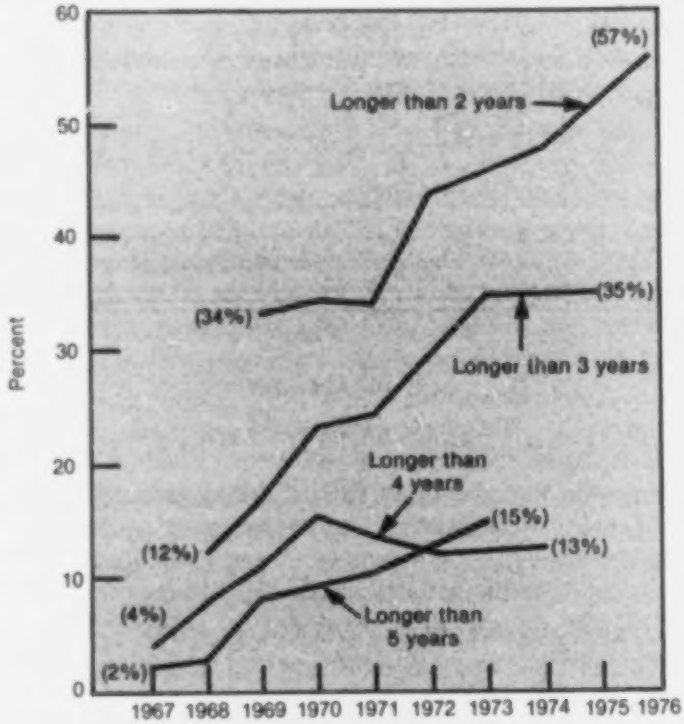
[43] *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983,* NSF 85-300 (Washington, DC: National Science Foundation, 1985), table A-33, p. 52.

[44] Ibid., table C-35, p. 138.

[45] National Research Council, *Postdoctoral Appointments,* op. cit.

[46] Ibid., pp. 85-108.

Figure 3-18.—Percent of Bioscientists Planning Postdoctoral Study Who Had Held Appointments Longer Than 2 to 5 Years, by Year of Doctorate



SOURCE: National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, D.C.: National Academy Press, 1981), p. 89.

at a major research university and involved in research than its nonpostdoctoral counterpart, but far less likely to have received tenure. (See tables 3-4, 3-5, and 3-6.) It also found that nonpostdoctorals earned 3 to 10 percent more than their postdoctoral counterparts. These last two effects are partially explained by the delay in obtaining a position caused by the time spent at the postdoctoral level. The magnitude of the effect was so large in the biosciences, however, that NRC expressed concern over "whether the postdoctoral experience has been advantageous to those pursuing careers in research." It reported "frustrations" among young bioscientists caught in a "postdoctoral holding pattern," as exemplified by the following quote:[47]

> Frankly, many of us are concerned about our future prospects in these times, after many years of training. We are becoming increasingly discouraged by the decline of tenure-track positions and the increasing difficulty in obtaining grant support. An opinion that is often expressed is that we postdocs provide a cheap labor source for "established" investigators. Especially in recent years many of us have been completely bypassed by the economic trends, so that

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[47] Ibid., p. 93.

Table 3-4.—Comparison of 1979 Employment Situations of Fiscal Year 1972 Bioscience Ph.D. Recipients Who Took Postdoctoral Appointments Within a Year After Receipt of Their Doctorates With the Situations of Other Fiscal Year 1972 Graduates Who Have Never Held Appointments

	Took postdoctorate within year after graduation		Never held postdoctorate	
Employment position in 1979	Number	Percent	Number	Percent
Total 1972 bioscience Ph.D.s[a]	1,571	100	1,472	100
Major research universities[b]	446	28	230	16
Tenured faculty	77	5	130	9
Nontenured faculty	281	18	69	5
Nonfaculty staff	88	6	31	2
Other universities and colleges	548	35	649	44
Tenured faculty	116	7	410	28
Nontenured faculty	369	24	195	13
Nonfaculty staff	63	4	44	3
Nonacademic sectors	537	34	580	39
FFRDC Laboratories	30	2	12	1
Government	171	11	243	16
Business/industry	183	12	214	14
Other sectors	153	10	111	8
Unemployed and seeking job	40	2	13	1

[a] Excludes graduates not active in the labor force in 1979.

[b] Included are 59 universities whose total R&D expenditures in 1977 represented two-thirds of the total expenditures of all universities and colleges.

NOTE: Percentage estimates reported in this table are derived from a sample survey and are subject to an absolute sampling error of less than 5 percentage points.

SOURCE: National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy Press, 1981), p. 92.

> we have been unable to purchase homes, have families, etc., while pursuing advanced training necessary to secure a " respectable position." For many of us it is becoming reasonable to ask: "Is it worth it?"

In summary, NRC found that "postdoctorals continue to play an important role in the nation's research enterprise," and are "an invaluable mechanism for strengthening and confirming the research potential of the young investigator." However, NRC found "some serious concerns . . . regarding the present and future role of postdoctorals in the research community." These were:[48]

1. the lack of prestige and research independence in postdoctoral appointments for the most talented young people;
2. the mismatch between the important role that postdoctorals play in the Nation's research enterprise and the lack of opportunities that they find for subsequent career opportunities in research;
3. the lack of recognized status of postdoctoral appointments in the academic community; and
4. the underutilization of women and members of minority groups in scientific research.

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[48] Ibid.

Table 3-5.—Comparison of 1979 Employment Situations of Fiscal Year 1972 Physics Ph.D. Recipients Who Took Postdoctoral Appointments Within a Year After Receipt of Their Doctorates With the Situations of Other Fiscal Year 1972 Graduates Who Have Never Held Appointments

Employment position in 1979	Took postdoctorate within year after graduation		Never held postdoctorate	
	Number	Percent	Number	Percent
Total 1972 physics Ph.D.s[a]	557	100	632	100
Major research universities[b]	115	21	46	7
Tenured faculty	28	5	19	3
Nontenured faculty	53	10	19	3
Nonfaculty staff	34	6	8	1
Other universities and colleges	132	24	166	26
Tenured faculty	49	9	113	18
Nontenured faculty	63	11	41	6
Nonfaculty staff	20	4	12	2
Nonacademic sectors	308	55	418	66
FFRDC Laboratories	91	16	82	13
Government	71	13	107	17
Business/industry	126	23	186	29
Other sectors	20	4	43	7
Unemployed and seeking job	2	0	2	0

[a] Excludes graduates not active in the labor force in 1979.

[b] Included are 59 universities whose total R&D expenditures in 1977 represented two-thirds of the total expenditures of all universities and colleges.

NOTE: Percentage estimates reported in this table are derived from a sample survey and are subject to an absolute sampling error of less than 5 percentage points.

SOURCE: National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy Press, 1981), p. 92.

SUPPLY OF AND DEMAND FOR ENGINEERING FACULTY

Unlike the rest of academia where the demand for new faculty has been and will continue to be weak, engineering departments appear to be suffering from a surplus of unfilled faculty slots. Those concerned with engineering education and the health of American engineering feel that the lack of sufficient faculty is the most important deterrent to increasing the quality, scope, and number of engineering programs. For several years, the engineering community has been referring to the growing faculty shortage problem as the most immediately pressing problem facing engineering education. Undergraduate engineering enrollments have more than doubled in the past decade. In addition, graduate enrollments have nearly doubled. Meantime, full-time engineering faculty rose 14 percent and part-time engineering faculty rose 20 percent.[49] These trends have raised the student faculty ratio from

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[49] American Association of Engineering Societies, *Engineering and Technology Enrollments, Fall 1983* (New York: American Association of Engineering Societies Publications, 1984). Data was derived from the 16th annual survey of engineering and technology enrollments conducted by the Engineering Manpower Commission of AAES.

Table 3-6.—Comparison of 1979 Employment Situations of Fiscal Year 1972 Chemistry Ph.D. Recipients Who Took Postdoctoral Appointments Within a Year After Receipt of Their Doctorates With the Situations of Other Fiscal Year 1972 Graduates Who Have Never Held Appointments

	Took postdoctorate within year after graduation		Never held postdoctorate	
Employment position in 1979	Number	Percent	Number	Percent
Total 1972 chemistry Ph.D.s[a]	941	100	615	100
Major research universities[b]	142	15	18	3
Tenured faculty	42	4	18	3
Nontenured faculty	64	7	0	0
Nonfaculty staff	36	4	0	0
Other universities and colleges	119	13	166	27
Tenured faculty	25	3	117	19
Nontenured faculty	79	8	41	7
Nonfaculty staff	15	2	8	1
Nonacademic sectors	680	72	416	68
FFRDC Laboratories	38	4	0	0
Government	78	8	86	14
Business/industry	501	53	287	47
Other sectors	63	7	43	7
Unemployed and seeking job	0	0	15	2

[a] Excludes graduates not active in the labor force in 1979.

[b] Included are 59 universities whose total R&D expenditures in 1977 represented two-thirds of the total expenditures of all universities and colleges.

NOTE: Percentage estimates reported in this table are derived from a sample survey and are subject to an absolute sampling error of less than 5 percentage points. See app. G for a description of the formula used to calculate approximate sampling errors.

SOURCE: National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy Press, 1981), p. 92.

12:1 to 20:1, after adjusting for faculty research commitments. (In 1973 there were 235,000 full-time equivalent engineering undergraduate and graduate students and 19,400 FTE engineering faculty not involved exclusively in research. By 1983 those numbers had increased to 486,400 FTE students and 24,800 FTE faculty.[50]) If the number of engineering majors stays constant or slows in its increase, the alleged shortage will eventually abate. Engineering enrollment was actually down 2.8 percent in 1984 from 1983.[51]

Many in the engineering community argue that the increase in the student to faculty ratio has significantly reduced the quality of engineering education and may be forcing faculty to pursue nonacademic positions. Surveys conducted by the Engineering Manpower Commission for the Engineering College Faculty Project reported that faculty shortages had resulted in higher teaching loads and some curtailment of course offerings.[52] It is important to note that there is no consensus that the rising student to faculty ratio has had a major impact on the quality of engineering B.S. recipients. Robert Armstrong of DuPont has publicly stated that industry does not see this as a problem, as have others.[53]

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[50] *Academic Science/Engineering: Scientists and Engineers*, NSF 84-309 (Washington, DC: National Science Foundation, 1983), table B-1, p. 6 for faculty. All figures multiplied by 0.78 to eliminate FTEs devoted purely to research (same source, table A1A, p. 78); U.S. Congress, House, "Testimony of David R. Reyes-Guerra, P.E., Executive Director, Accreditation Board for Engineering and Technology," Committee on Science and Technology (Washington, DC: U.S. Government Printing Office, July 24, 1985), chart D for enrollments.

[51] U.S. Congress, House, "Testimony of David R. Reyes-Guerra," op. cit., chart D.

[52] McPherson, "The State of Academic Labor Markets," op. cit., pp. 18-19.

The extent of the shortage varies, depending on the manner in which it is calculated. According to NSF there are nearly 29,000 engineers employed full-time at universities and colleges and an additional 8,800 employed part-time.[54] A 1983 survey of engineering faculty and graduate students by the American Society for Engineering Education (ASEE) reported that 8.5 percent of the authorized full-time faculty positions were unfilled in the fall of 1983 as compared to 7.9 percent in 1982.[55] However, Edward Lear, executive director of the ASEE, estimates that the shortage is actually about 20 to 25 percent. He claims that to restore the ratio of faculty to students that existed in the late 1960s would require an additional 6,000 faculty in the engineering colleges.[56] Lear claims that the true shortage is understated because administrators will not authorize positions, even if they are needed, if there is no prospect of their being filled.

On the other hand, Sue Berryman, a social scientist at the Rand Corp., analyzed NSF data on academic engineering and found a possible shortage of computer science faculty but not of electrical engineering faculty. She bases this finding on an examination of comparative salaries, tenure rates, and rates of resignation among the different science and engineering fields. Even if there is a shortage of computer science faculty, Berryman points out, the implications of such a shortage are uncertain. She notes that many of the academic requirements for computer science can be fulfilled in courses other than computer science.[57]

Another finding that raises questions about the seriousness of the engineering faculty shortage problem comes from the NRC survey of doctorate recipients. According to that survey, the number of engineering doctorate recipients reporting definite postgraduation plans for academic employment declined between 1973 and 1979 and has only returned to its earlier level in 1983. If engineering doctorate recipients are as much in demand by engineering departments as the engineering professions claim, the number reporting definite academic plans should have increased substantially.

The NRC data also reveals that the proportion of engineering doctorate recipients without firm plans at the time of receipt of the doctorate is about the same as that for all other fields and has remained constant over the past decade. In 1983, 27.6 percent of the engineers reported that they were still seeking appointments as their doctoral studies were completed, the same percentage as in 1973, while 27.1 percent of all doctorate recipients made the same report. If the competition for engineering Ph.D.s between academia and industry were as strong as some claim, the proportion of engineers without definite employment plans should be lower than that for all other fields and should be decreasing.[58]

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[53] National Research Council, *Labor Market Conditions for Engineers: Is There a Shortage?* (Washington, DC: National Academy Press, 1984), ch. 1, p. 122.

[54] *Academic Science/Engineering: Scientists and Engineers,* op. cit., p. 83, and table B-1, p. 6.

[55] Paul Doigan, "ASEE Survey of Engineering Faculty and Graduate Students, Fall 1983," *Engineering Education,* October 1984, p. 50.

[56] National Research Council, *Labor Market Conditions,* op. cit., p. 115.

[57] Sue E. Berryman, "The Adjustments of Youth and Educational Institutions to Technologically-Generated Changes in Skill Requirements," National Commission for Employment Policy, May 1985.

Setting aside considerations of the magnitude of the shortage problem, administrators claim that engineering departments are increasingly dependent on hold-over retirees who will soon leave the system entirely, on part-time personnel chosen more for their availability than for their expertise, and on foreign nationals (some of whom are thought to be underqualified because of alleged language and cultural problems). Universities claim that the reasons they cannot recruit the best engineers to teach are the relatively lower salaries of faculty versus those found in business and the lack of state-of-the-art equipment for research. Daniel Drucker of the University of Florida claims that the fundamental problem is one of quality. Not enough of the top-quality engineering undergraduates are pursuing the Ph.D., and of those who do, not enough want to teach.[59]

There are signs, however that the situation is improving. The ASEE Report in 1983 showed that 35.8 percent of institutions reported an increase in their ability to recruit and retain faculty—up from 16.5 percent in 1981.[60] Unfilled engineering faculty positions at the professor level in 1982 were only 2.9 percent, below the estimated academic norm. The biggest problem seemed to exist at the assistant professor level where 24.4 percent of the budgeted positions were reported vacant. At higher levels there actually appears to be a net flow of engineers *into* the universities; i.e., more engineers leaving industry for academia than *vice-versa*. Electrical engineering experienced the greatest influx of new faculty members from industry, with the gain exceeding the loss by more than 150 percent.[61]

Increasingly, the rewards for university positions are becoming more attractive. The Survey of Deans conducted by AAES/ASEE documented that many universities were providing differential salary treatment for engineering faculty for purposes of recruitment and retainment. Increases awarded to engineering faculty were over and above normal, regularly scheduled university-wide salary adjustments. Engineering faculty salaries have risen 7 to 10 percent per year recently, while nonacademic engineers have received raises on the order of 2.8 percent per year.[62]

The relationship of academic salaries to nonacademic salaries is illustrated in figure 3-19 showing academic and industrial salaries for engineering Ph.D.s. The figure shows that only supervisory engineers receive higher salaries than their academic counterparts at the full professor level, but that junior academics do not fare nearly as well as junior industrial engineers.

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[58] National Research Council, *Summary Report 1983: Doctorate Recipients From United States Universities* (Washington, DC: National Academy Press, 1983), p. 19.

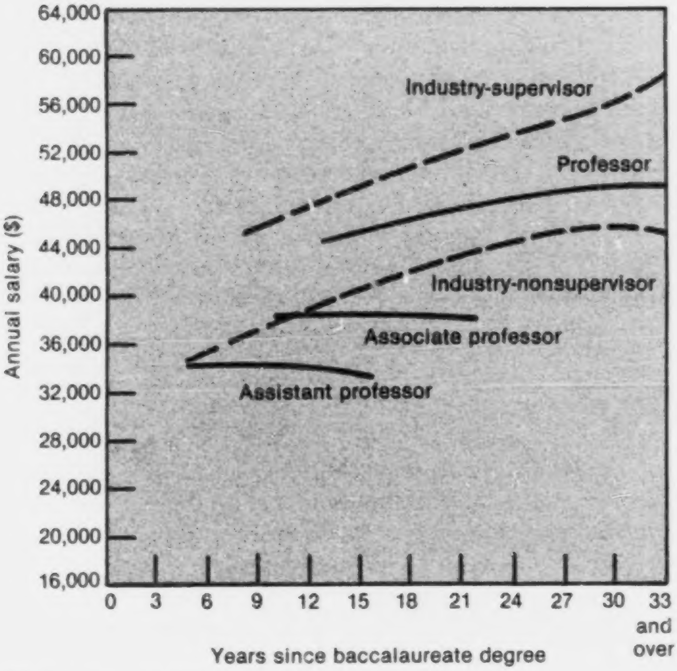
[59] National Research Council, *Labor Market Conditions*, op. cit., p. 113.

[60] Doigan, op. cit., p. 52.

[61] American Association of Engineering Societies/American Society for Engineering Education, *Final Report: Engineering College Faculty Shortage Project* (Washington, DC: American Society for Engineering Education, November 1983), p. 10.

[62] National Research Council, *Labor Market Conditions*, p. 118.

Figure 3-19.—Comparison of Academic-Industry Engineering Ph.D. Salaries (All Professional Salaries Adjusted to 11-Month Basis)



SOURCE: Engineering Manpower Commission, AAES, 1983.

Figure 3-19 displays median academic salaries for a 9-month period, augmented by a 2-month summer grant, which is received by most faculty. These data may be deceiving, as they do not include compensation received by faculty for consulting. Robert Weatherall of MIT reports that electrical engineering graduates who received Ph.D.s in 1967 and joined faculties were receiving more financial compensation from all sources, including consulting, than their counterparts in industry. Weatherall concludes that graduate students are disturbed more by a lack of equipment and resources than by salary differentials.[63]

A survey conducted by the College and University Personnel Association found that engineering faculty earned higher salaries in public institutions than in private institutions during the 1983-84 school term.[64] Yet, according to the ASEE survey reported above, there were more unfilled vacancies in the public schools than in private schools. This finding also calls into question the claim that the salary differential is the principal disincentive to a career in academia.

Many in the engineering community believe that the number of doctorate awards must be increased in order to reduce the impacts of shortages of engineering faculty. Fortunately, the number of doctorates awarded annually in engineering has been rising steadily since 1980.* Engineering doctorate degrees increased by 4.8 percent in 1984,[65] when all other disciplines, except for the physical sciences, experienced declines.[66] Full-time enrollment of U.S. graduate students in engineering has risen for the past 3 years.[67]

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[63] Ibid., pp. 118-119.

[64] Scientific Manpower Commission, *Manpower Comments*, vol. 21, No. 3, April 1984, p. 16.

Some question the extent to which undergraduate engineering education is necessarily dependent on doctoral level faculty to accomplish its mission. The Panel on Engineering Graduate Education and Research of the National Research Council Committee on the Education and Utilization of the Engineer concluded in their 1985 report that schools that emphasize undergraduate education can safely utilize faculty without the doctorate. However, the "faculty in research universities should, in the overwhelming majority, have doctor's degrees."[68]

In conclusion, there appears to be some disagreement about the actual need for academic engineers. Documented shortages are much lower than shortages determined on the basis of some ideal quality of education. In addition, the shortages are more apparent at some faculty levels, particularly entry levels, and in particular disciplines, such as computer science. These shortages have occurred more because of skyrocketing undergraduate enrollments in engineering than because of the decline in the number of engineers seeking Ph.D.s and subsequent academic appointments. If universities and colleges continue to allow high enrollments in engineering in response to perceived market signals, then faculty shortages will continue, particularly if academe continues to rely only on field-specific, U.S. educated doctorate recipients as their primary source for academic faculty. Some academic institutions have already begun to cap their undergraduate engineering enrollments in an attempt to relieve the faculty shortage.

In addition, the literature suggests that one means of drawing more doctorate recipients into academe is through improvement of research facilities and equipment. The salary differential does not appear to be as important a disincentive as some would suggest; many young Ph.D.s prefer to conduct their research in industry because the facilities and equipment there are at the leading edge.

U.S. EDUCATION AND UTILIZATION OF FOREIGN SCIENTISTS AND ENGINEERS

Both as students and as faculty members, foreign nationals are a significant portion of the academic population, particularly in engineering, computer science, and the physical sciences. Foreign students comprised 6.2 percent of the undergraduate enrollment in engineering, and 35 percent of the graduate enrollment. Their overall participation in all of higher education enrollment is less than 3 percent, demonstrating their disproportionate participation in engineering education.[69] One-fourth of all graduate students who are foreign nationals are enrolled in engineering programs.

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*The percentage of foreign nationals enrolled in doctoral engineering programs has remained constant at approximately 41 percent during this time period.

[65] Patrick Sheridan, "Engineering Enrollments, Fall 1983," *Engineering Education*, October 1984, p. 46.

[66] National Research Council, *Doctorate Recipients, 1983*, op. cit., see table A and figure 2.

[67] Doigan, op. cit., p. 54.

[68] National Research Council, *Engineering Graduate Education and Research* (Washington, DC: National Academy Press, 1985), p. 103.

There has been a steady increase in enrollment of foreign students since 1964, when total foreign enrollment in U.S. institutions of higher education was 1.5 percent.[70] (See figure 3-20.) A Report of the Institute of International Education concluded that foreign students enroll proportionately more often in engineering and the medical sciences, and less often in the humanities and social sciences. This can be attributed to the unavailability in developing countries of costly training facilities necessary for engineering and medical science education.[71] Since 1979, the regional origin of engineering students has changed dramatically. The proportion of South and East Asians nearly doubled between 1979 and 1984, while the proportion of students from the Middle East declined by 17 percent. Data from 1984 show that South and East Asians constitute nearly 60 percent of foreign *graduate* engineering students, and 32 percent of foreign *undergraduate* engineering students. Middle Easterners comprise 18 percent of the foreign *graduate* engineering population and 38 percent of the foreign *undergraduate*

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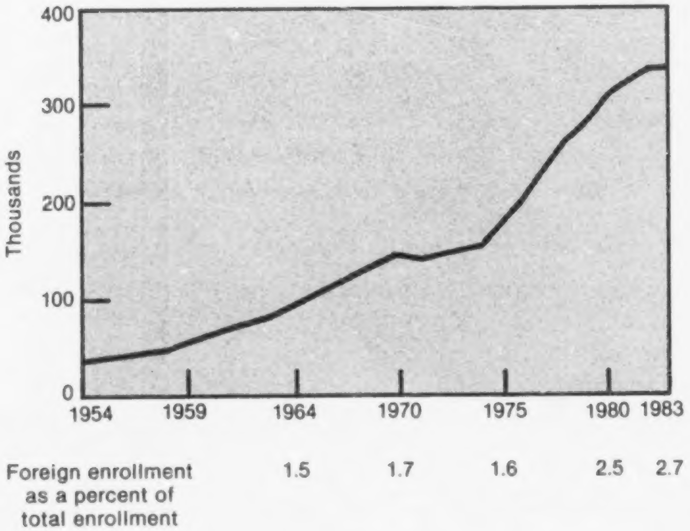
[69] *Participation of Foreign Citizens in U.S. Science and Engineering* (Washington, DC: National Science Foundation, January 1985).

[70] Ibid., p. 7.

[71] Elinor G. Barber (ed.), *Foreign Student Flows*, IIE Research Report No. 7 (New York: Institute of International Education, 1985), pp. 40-42.

Figure 3-20.—Total Foreign Enrollment in U.S. Institutions of Higher Education



NOTE: Includes students at all levels.

NOTE: Includes students at all levels.

SOURCE: Institute of International Education and National Center for Education Statistics.

Table 3-7.—Origin of Foreign Students Within Fields of Study, 1983-84

	World region								Number of students reported
	Africa	Europe	Latin America	Middle East	North America	Oceania	South and East Asia	Total	
Agriculture	26.6	5.5	27.9	8.7	4.1	1.0	26.3	100.1	4,993
Business and management	16.1	8.6	17.8	12.3	4.2	1.3	39.7		37,939
Education	16.5	9.7	17.1	13.2	10.8	4.1	28.7		7,944
Engineering	7.0	6.5	12.22	30.1	1.8	0.2	42.2		43,261
Fine and applied arts	15.8	6.5	21.2	16.5	4.8	0.5	34.5		4,185
Health sciences	16.5	9.9	18.8	14.3	9.8	2.3	28.4		8,814
Humanities	9.6	21.4	14.4	6.8	9.7	2.5	35.6		8,490
Math/computer science	6.4	7.1	13.0	17.2	1.5	0.7	54.1		18,993
Physical/life sciences	10.6	11.4	12.8	14.3	4.3	0.9	45.7		15,888
Social sciences	6.8	16.4	18.2	10.7	11.0	2.1	34.8		7,739
Other	14.4	12.9	17.8	11.1	7.5	1.6	34.7		7,400
Intensive English language	2.9	5.4	22.5	26.5	0.5	0.0	2.0		3,296
Undeclared	10.3	16.1	19.1	12.8	9.3	1.3	31.2		8,108
All fields	11.4	9.6	15.8	17.4	4.8	1.2	39.9		177,050

SOURCE: National Science Foundation

engineering population.[72] Table 3-7 shows world region of origin of foreign students in the sciences and engineering undergraduate and graduate levels combined.

Data for 1983 from AAES show that at the Ph.D. level, 41.5 percent of total full-time engineering candidates were foreign nationals, up slightly from 41 percent in 1982.* The National Research Council Survey of Doctoral Recipients (1983) shows that the percentage of engineering doctoral recipients listing U.S. citizenship has declined from 82 percent in 1965 to just under 48 percent in 1983.[73] In comparison, in 1983, non-U.S. citizens received more than a third of the doctoral degrees awarded in mathematics, 28 percent of physics and astronomy doctorates, 21 percent of the chemistry doctorates, and 12 percent of the doctorates in the biological and health sciences (down from 14 percent in 1975).

In the doctoral population, available information from various sources indicate that between 20 and 50 percent of foreign doctoral students in the sciences are principally supported through research or teaching assistantships. In engineering, the proportion is nearly 60 percent.[74] It is uncertain whether this deprives qualified U.S. students of research training and financial support. Analysts Lewis Solmon and Ruth Beddow found that, "foreign students probably pay more than their education costs, and they might be paying substantially more."[75] Solmon and Beddow did not include U.S. research assistantship or fellowship support in their analysis, however.

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[72] Marianthi Zikopoulos and Elinor G. Barber (eds.), *Profiles: Detailed Analyses of the Foreign Student Population, 1983/1984* (New York: Institute of International Education, 1985), pp. 30-39.

*In base numbers, in 1982 there were 6,741 foreign nationals among the 16,442 engineering doctorate enrollees; in 1983, 7,687 of the total 18,540 doctoral candidates were foreign nationals.

[73] National Research Council, *Summary Report 1983: Doctorate Recipients From United States Universities* (Washington, DC: National Academy Press, 1983), see table D.

[74] Betty Vetter, "U.S. Education and Utilization of Foreign Scientists and Engineers," contractor report prepared for the U.S. Congress, Office of Technology Assessment, 1985.

Proponents of U.S. education assistance to foreign nationals justify it with the following reasons; it is a means of helping persons from less fortunate nations to obtain the benefits of a U.S. education; the political advantage of having future leaders of other countries educated in the United States, rather than elsewhere will pay off in the long run; it is to the cultural and sociological advantage of U.S. students to be exposed to persons from other parts of the world; and the United States can utilize the skills and training of those individuals who stay on in this country after their educational training has ended. Opponents are concerned that the training and employment of foreign nationals in the United States constitutes a "brain-drain" from the home country if they remain here, and could pose a threat to our national security, if they return home. Restricting access to "sensitive" research at U.S. universities may provide additional problems to those research institutions with large numbers of foreign students and faculty members.

There is disagreement between various groups in this country as to whether individuals admitted to the United States as students who complete a graduate degree here should be allowed to remain after completion of the degree (and perhaps a short period of further training). Increasing proportions of those earning doctorate degrees (56 percent in 1983) are remaining in the country after graduation.[76] Many employers, both in industry and in academic institutions, say that they cannot fill certain research and faculty positions with U.S. citizens, and available data verify this.[77] In 1984, major changes in immigration rules were proposed in legislation passed separately by both houses but not signed into law, both of which included an exception to the general rule that all foreign nationals in this country on a student visa be required to return to their native countries after graduation for 2 years before attempting to reenter the United States on a permanent visa. The exceptions would have allowed some scientists and engineers, as well as some other specialists, to accept employment and remain here. Universities and some industries felt sufficiently dependent on the foreign national population with U.S. graduate degrees that they lobbied Congress to include the exception allowing scientists and engineers to stay and accept employment in the United States.[78]

Others are concerned that the increasing number of foreign engineers earning degrees in this country are taking jobs at low pay in order to remain here, thus driving down salaries and reducing opportunities for U.S. members of the engineering profession. There is no statistical evidence that foreign engineers are paid less than comparably trained and experienced U.S. engineers.[79]

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[75] Lewis C. Solmon and Ruth Beddow, "Flows, Costs and Benefits of Foreign Students in the United States: Do We Have a Problem?" in Elinor Barber, op. cit., pp. 121-122.

[76] *Participation of Foreign Citizens*, op. cit., p. v.

[77] Michael G. Finn, "Foreign National Scientists and Engineers in the U.S. Labor Force, 1972-1982," a report to the National Science Foundation, March 1985, draft.

[78] Vetter, op. cit., p. 16.

[79] Vetter, op. cit., p. 17.

Foreign nationals are employed proportionately more often in educational institutions, specifically higher education, than U.S. citizens. This may be explained by the fact that scientists and engineers who are foreign nationals tend to have higher levels of educational attainment than U.S. scientists and engineers, as shown in figure 3-21. The proportion of foreign nationals engaged in research, development, and design is about the same as for U.S. scientists and engineers. The proportion of foreign nationals in management positions in R&D firms, however, is less than their U.S. counterparts. This may be a reflection of the fact that foreign nationals in the U.S. science and engineering labor force tend to be younger than the average U.S. scientist or engineer. Management positions traditionally go to senior employees.[80]

Many foreign nationals choose to enter the academic market after graduation. Because there is a shortage of faculty in engineering and in computer science and because an increasing proportion of U.S. doctoral graduates in these fields are foreign citizens, U.S. faculties include a large and increasing proportion of foreign nationals and foreign born but U.S. educated citizens. The current shortages of faculty in engineering schools would be far higher had they not been able to employ foreign engineers with U.S. Ph.D.s. A 1982 survey found that 18 percent of all full-time engineering faculty members earned their B.S. degrees from an institution outside the United States. The highest percentage of foreign born faculty is in computer science/engineering—20.7 percent. More than one-fourth (26 percent) of all assistant professors in engineering in 1982 earned their B.S. degrees outside the United States.[81]

Several authors have made reference to the "growing problem" of foreign nationals on engineering faculties. They contend that the drawbacks of an increasingly foreign born faculty are the limitations in their communications skills and the implications for education. Some studies have found that a number of problems for women are greatly exacerbated when they deal with foreign faculty and foreign students.[82] The classroom climate for women who must deal with foreign male faculty and graduate students is particularly difficult when such faculty and students come from countries where women, by statute or custom, have a very restricted role. These difficulties are further emphasized by the fact that 92.5 percent of all foreign students in engineering are male.

In conclusion, there is no apparent national policy in regard to either the education or the utilization of foreign students and graduates, against which either current or proposed regulations for the temporary or permanent entry of foreign science and engineering students or foreign scientists and engineers might be tested. Foreign students make up a significant fraction of graduate enrollments in U.S. universities, where they serve as research assistants, and to a lesser degree, as teaching assistants. As these

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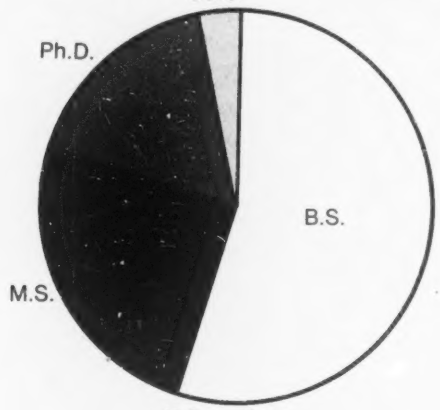
[80] Finn, op. cit., p. 12.

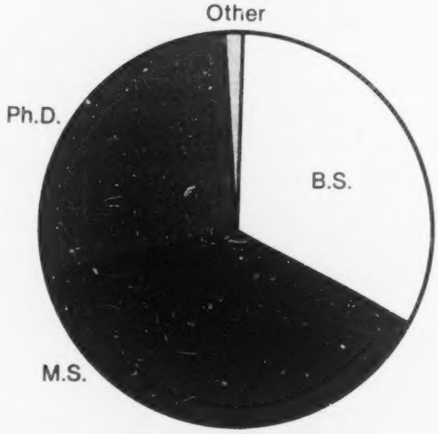
[81] Vetter, op. cit.

[82] Scientific Manpower Commission, *The International Flow of Scientific and Technical Talent: Data, Policies and Issues*, proceedings of a joint meeting of the Scientific Manpower Commission and the Engineering Manpower Commission on May 7, 1985, in preparation for publication, 1985.

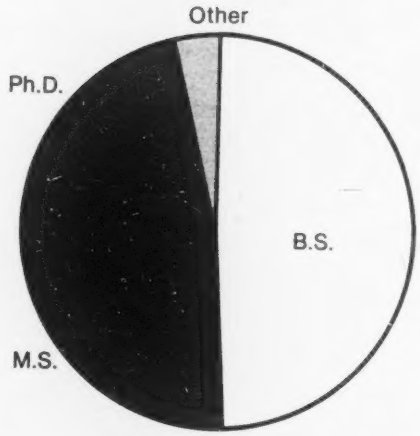
Figure 3-21.—Educational Attainment of Scientists and Engineers, by Immigrant Status, 1982



U.S. natives



Foreign nationals



Naturalized U.S. citizens

SOURCE: ORAU, based on 1982 Postcensal survey (Finn).

students obtain advanced degrees, many seek to remain in the United States and to enter the U.S. labor force, which appears to be problematic only in academe, where communication skills are essential. There is no doubt that foreign born scientists have enriched U.S. accomplishments and achievements in science and technology. As these individuals increasingly enter American industry and academe, following an education in American colleges and universities, a new set of policy issues arise. Issues of interest to policymakers are the purposes of educating students from other nations, whether the education of American students suffers from the participation of foreign nationals, and the cost, if any, to the taxpayers of educating foreign students.

Chapter 4: The Industrial Market for Engineers

As shown in chapter 2, most science bachelor's degree recipients either go on to graduate school—the Ph.D. being the true entry-level degree for a research career—or obtain employment in a nonscience field (see chapter 2, table 2-2). More than three-quarters of all engineering B.S. recipients, by contrast, obtain immediate employment as engineers in industry. In addition, more than 90 percent of all the job offers to all science and engineering bachelor's graduates in 1984 were in engineering, engineering technology, or computer science (see figure 4-1).[1] Therefore, when considering the utilization of science and engineering bachelor's degree holders, it is appropriate to focus on the industrial market for engineers.

According to the Bureau of Labor Statistics (BLS), the number of employed engineers in the United States doubled between 1960 and 1982, increasing from 800,000 to more than 1,600,000 (see figure 4-2).[2] During that same period, 1960-82, the U.S. gross national product (GNP) increased by 100 percent in constant dollars and the national research and development (R&D) budget grew by 103 percent in constant dollars. Thus, the growth in demand for engineers appears to correlate very well with growth in GNP and growth in total national expenditures for R&D.

The number of first year enrollments in engineering school and the number of engineering bachelor's degree recipients has fluctuated quite widely since World War II, with peaks and troughs apparently produced by transitory political and social events and trends (see figure 4-3).[3] However, beneath the fluctuations, there appears to be an overall trend of an increase of slightly less than 3 percent per year in the number of engineering B.S.s awarded each year. The recent surge in engineering B.S.s awarded in 1980 to 1983 appears to be something of an aberration, that could be followed by a decline in the late 1980s, since all previous peaks have been followed by troughs.

The growth in engineering B.S.s has been somewhat uneven across fields, with electrical and mechanical engineers showing the greatest increases over the past decade, as can be seen from figure 4-4.[4] The number of aerospace,

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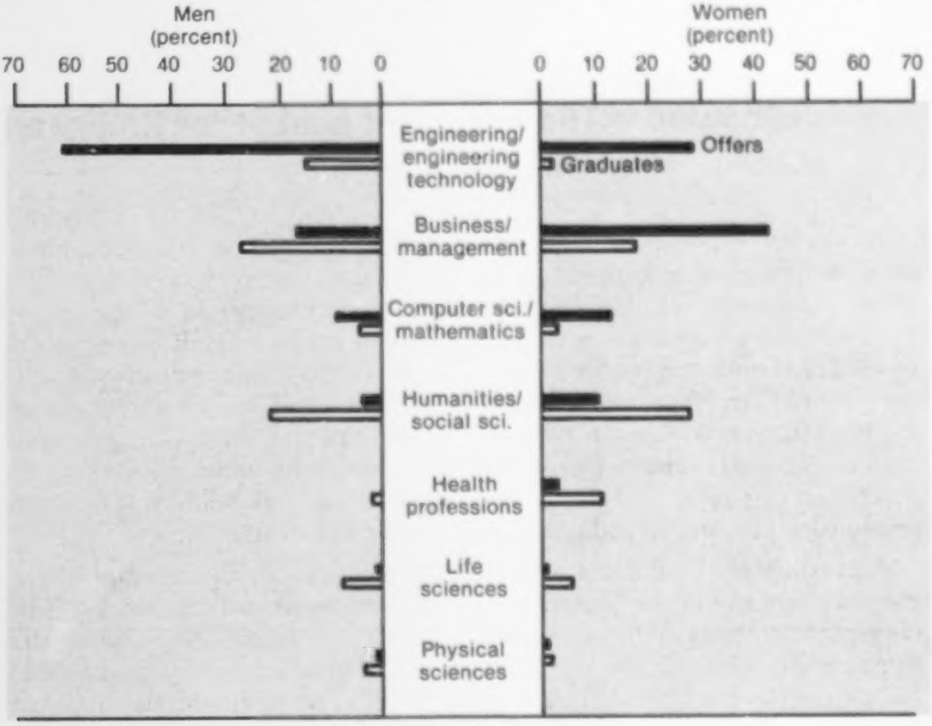
[1] *Opportunities in Science and Engineering: A Chartbook Presentation* (Washington, DC: Scientific Manpower Commission, November 1984), p. 32.

[2] *Engineering Education and Practice in the United States* (Washington, DC: National Research Council, 1985), p. 88. It should be noted that there is a serious discrepancy between BLS and NSF data on employed engineers, the latter showing 1,847,000 engineers employed in 1982, *Science Technology Resources*, NSF 85-305 (Washington, DC: National Science Foundation, January 1985), p. 545.

[3] *Engineering Education and Practice in the United States,* op. cit., p. 52.

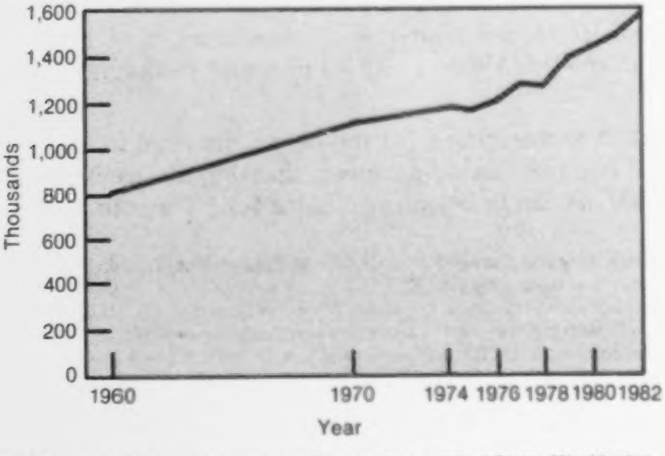
[4] Robert C. Dauffenbach and Jack Fionto, "The Engineering Degree Conferral Process: Analysis Monitoring and Projections," report for the Engineering Manpower Commission, November 1984, p. 13.

Figure 4-1.—Percent of All Offers and Percent of All Bachelor's Graduates



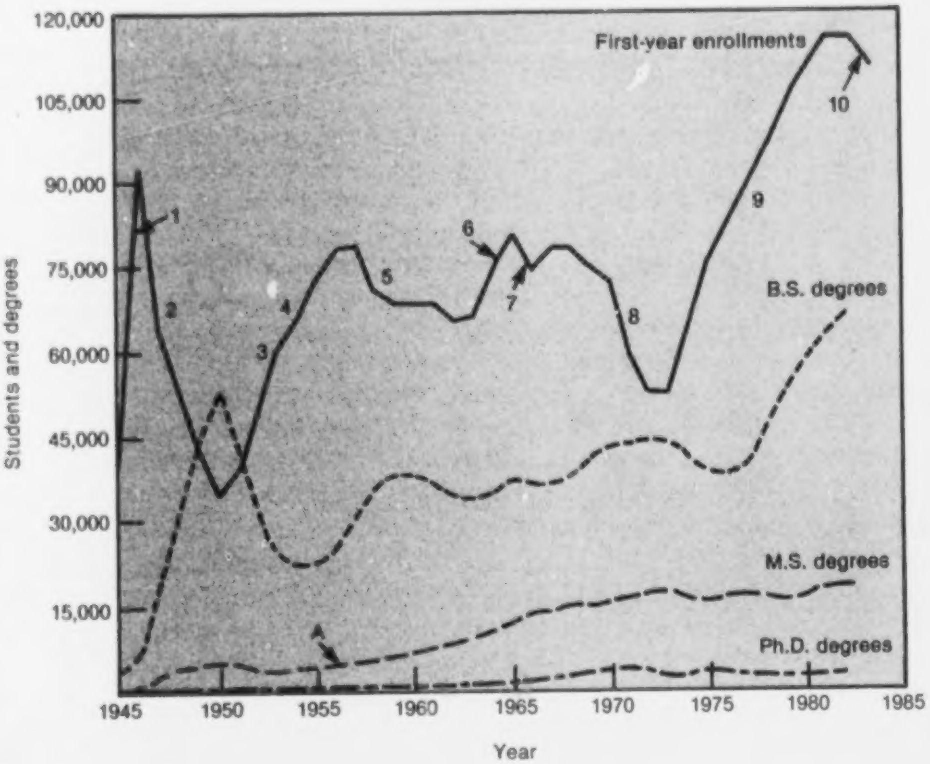
SOURCE: *Opportunities in Science and Engineering* (Washington, DC: Scientific Manpower Commission, 1984), p. 32.

Figure 4-2.—Employed Engineering Personnel, 1960-82



SOURCE: *Engineering Education and Practice in the United States* (Washington, DC: National Research Council, 1985), p. 88.

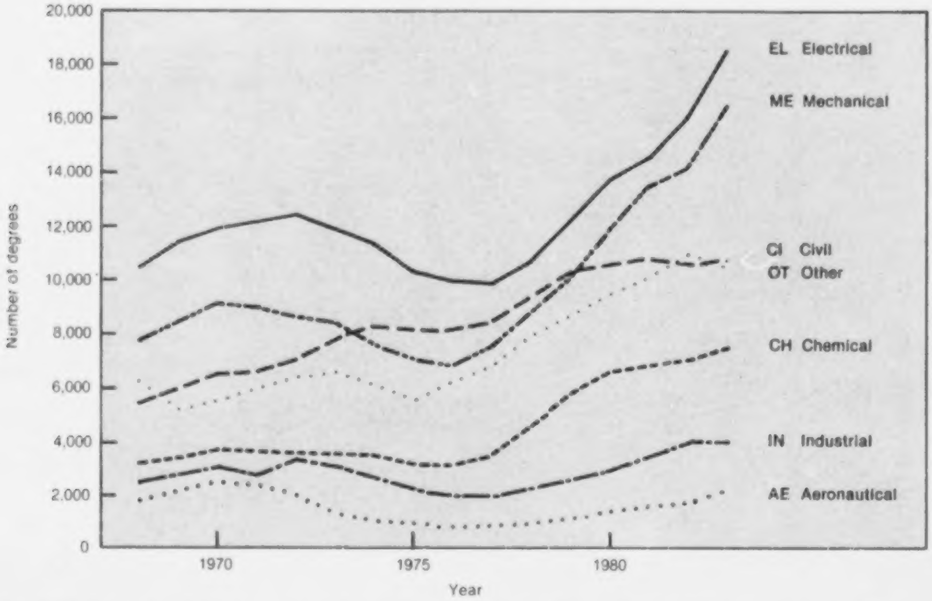
Figure 4-3.—Engineering Freshman Enrollments, B.S., M.S., and Ph.D. Degrees



1 Returning World War II veterans
2 Diminishing veteran pool and expected surplus of engineers
3 Korean War and increasing R&D expenditures
4 Returning Korean War veterans
5 Aerospace program cutbacks and economic recession
6 Vietnam War and greater space expenditures
7 Increased student interest in social-program careers
8 Adverse student attitudes toward engineering, decreased space and defense expenditures, and lowered college attendance
9 Improved engineering job market, positive student attitudes toward engineering, and entry of nontraditional students (women, minorities, and foreign nationals)
10 Diminishing 18-year-old pool
A ASEE Evaluation Report recommends greater stress on math/science and quality graduate education

SOURCE: *Engineering Education and Practice in the United States* (Washington, DC: National Research Council, 1985), p. 52.

Figure 4-4.—B.S. Engineering Degrees, 1968-83



SOURCE: Robert Dauffenbach and Jack Fronto, "The Engineering Degree Conferral Process Analysis, Monitoring and Projections," report to Engineering Manpower Commission, 1984, p. 13.

chemical, industrial, and mining and petroleum engineering B.S.s have also increased dramatically, more than doubling for each field since 1976. Only civil engineering failed to show a dramatic increase in the 1976-83 period, perhaps because it was the only field not to suffer a decline in the early 1970s.

SHORTAGES: PRESENT AND FUTURE

The principal industrial employers of engineers are companies that make transportation equipment (11 percent); communication equipment (6 percent); electronic components (3 percent); and office, computing, and accounting machinery (5 percent). Other major employers include engineering companies (10 percent) and the government (12 percent). Many engineering employers have reported shortages of engineers, especially in the electrical and computer specialties (CS). The National Science Foundation (NSF) annually surveys about 300 major industrial employers of engineers. The table below reports the percentage of surveyed companies reporting a "shortage" of either electrical or computer engineers.[5] (NSF defines a shortage as a situation where an employer has "more vacancies than qualified job applicants in a specific field.") Note the dramatic decline in the number of firms reporting shortages between 1981 and 1983.

	Electrical engineers	*Computer engineers*
1981	57 percent	51 percent
1982	31 percent	21 percent
1983	7 percent	6 percent
1984	19 percent	15 percent

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[5] "Shortages Increase for Engineering Personnel in Industry," *Science Resource Studies Highlight* (Washington, DC: National Science Foundation, Mar. 29, 1985).

Other surveys report similar results. The 1983 American Electronics Association (AEA) survey of 815 firms employing engineers found that 32 percent reported a shortage of electrical and CS engineers.[6] A similar study conducted among Massachusetts electrical engineer (EE) employers in 1983[7] found 25 percent reporting shortages of "entry-level" electrical engineers while 65 percent reported shortages of experienced EEs.

The key question for policy purposes is whether shortages of engineers will be a problem in the future. This question is especially difficult to answer when it is not clear how much of a problem shortages cause at the present time. Shortage reports do not describe the adjustments that employers and potential employees make to shortage situations. Employers have many options available to them, including hiring less qualified personnel and training them; raising wages to bid away engineers from other companies; and rearranging jobs and tasks to better utilize engineering talent. It is clear that such adjustments take place, but there is less clarity about the consequences. Some adjustments may be relatively painless, while others may create as many problems as the original shortages did.

Employees also have options available for dealing with shortage or surplus situations. They can, within limits, move to related and more profitable fields, or seek training in those specialties which are experiencing shortages. The interfield mobility of scientists and engineers, and relative responsiveness of undergraduates to market signals, are two important characteristics of the U.S. scientific and technical work force.

In order to evaluate the possibility and effects of engineer shortages over the rest of the decade, therefore, it is not enough to simply project supply and demand. It is also necessary to understand how employers and employees are likely to adjust to shortage and surplus situations. The principal purpose of this chapter is to lay out a framework for understanding these adjustments, and to summarize the (admittedly skimpy) evidence on their effects.

SUPPLY AND DEMAND PROJECTIONS

Supply and demand projections for engineers are the raw material for evaluating the extent of future engineering "shortages." In February 1984, the Office of Scientific and Engineering Personnel of the National Research Council (NRC) held a symposium on *Labor-Market Conditions for Engineers: Is There a Shortage*?[8] This symposium brought together the major sources of engineering supply and demand projections: BLS, NSF, and AEA.

All three projections used 1982-83 as their base year. BLS projected engineering jobs through 1995, using a sophisticated variant of the "manpower requirements" approach. First, BLS projected the growth rate of the whole economy and of individual industries. Then it calculated how many engineers would be needed to achieve this growth rate. These calculations were based on historical patterns of engineering employment, plus anticipated changes in these patterns in the future.

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[6] *Technical Employment Projections, 1983-87* (Palo Alto, CA: American Electronics Association, July 1983).

[7] Paul Harrington, et al., "Employment Developments in the Electrical Engineering Labor Market of Massachusetts and the U.S.," Northeastern University, 1983.

[8] *Labor Market Conditions for Engineers: Is There a Shortage?* (Washington, DC: National Research Council, 1984).

NSF used a similar methodology to predict the need for scientific, engineering, and technical personnel over the period 1982-87. Its model, however, gives more attention to specifying the course of defense spending than does BLS.

AEA took a totally different approach. They surveyed their members, asked them to project personnel needs—especially for engineers—through 1987. The individual needs were then totaled. This methodology has been criticized, by W. Lee Hansen and others, as being inherently unreliable. Most employers of engineers do not make firm projections of their manpower requirements beyond the next 18 months, so the responses to the AEA survey for the out-years are largely educated guesses. Moreover, respondents to surveys of this type tend to be overly optimistic about the relative market share their company is likely to achieve, and hence tend to overestimate their personnel requirements.

It must be emphasized that all three organizations were projecting the number of *new* engineering jobs. This is not the same as the *demand* for engineers. Employers not only have to fill new jobs, but they also have to fill vacancies caused by deaths, retirement, movement out of engineering into management or other jobs, or return to school. An accepted rule of thumb is that about 2 percent of the engineering work force will retire or die each year, creating new vacancies. Another 4 percent of engineers will transfer out of engineering into management or some other field. These are not small numbers. **In fact, the replacement demand in any year is considerably larger than the demand created by new job growth.** Thus, the magnitude of any "shortage" depends crucially on how these flows of people are treated.

Under the BLS moderate scenario for economic growth, the number of engineering jobs would increase by 3 percent per year, which is identical to the rate of growth in GNP assumed in the BLS model, and also to the historic rate of growth in the engineering profession. This growth rate translates into 45,000 new job openings each year. However, an additional 93,500 engineering jobs will have to be filled each year because of attrition and transfers.

NSF comes up with quite similar projections: an annual growth rate for engineering jobs of 2.6 to 4.5 percent. The low end of the range reflects an assumption of stagnant economic growth (real GNP growth rate of 2 percent) and low defense spending, while the high end reflects strong economic growth (real GNP growth of 4 percent and high defense spending).

AEA projections for demand are much higher: about 50,000 new engineering jobs each year within the electronics industry created alone. According to AEA, the electronics industry employs about one-third of all engineers. Consequently, AEA projections of demand, on an economy-wide basis, are three times higher than BLS and NSF estimates. These high projections clearly result from AEA's use of a questionable methodology.

Supply Projections

There are two major components to supply—new engineering graduates and transfers from other occupations. All three projections agree on the likely supply of entry-level engineers.

BLS and AEA project that the supply of entry-level engineers going into industry will average 63,000 annually, while NSF projects 65,000 to 69,000 annually. (All three projections fall substantially below the number of engineering undergraduate degrees actually awarded in 1983 and 1984 which were 72,471 and 76,931 respectively.[9])

The key difference is how these studies handle the transfer component of supply. BLS allows for transfers out of engineering (into other types of jobs or schools) but not transfers into engineering. Thus, BLS makes no attempt to calculate occupational mobility into engineering (though its existence and importance is acknowledged).

The NSF study, by contrast, makes two alternative assumptions about occupational mobility. In the first scenario, occupational mobility into engineering (and each of its subfields) is assumed to be equal to occupational mobility out of engineering. In the second scenario, it is assumed that occupational mobility into engineering takes place at its historic rate, which is just enough to bring supply and demand into balance. The AEA makes no assumption about the magnitude of interfield mobility.

Supply-Demand Gaps

What kinds of gaps between supply and demand for engineers do these projections imply? BLS compares the supply of new graduates to the demand for new jobs, and for replacements due to attrition and transfers and finds that supply only meets 46 percent of the demand for all engineers.

However, BLS is relatively sanguine about the implications of this gap. It points out that in 1980, the latest year with good figures, new entrants also filled less than one-half of total demand. (This was also true over the entire decade of the 1960s, according to OTA calculations.) BLS argues that the remainder came from:

> . . . transfers from other occupations; employed people with previous experience or training in engineering or a related occupation; recent science and math graduates; immigrant engineers; older engineers returning to the profession . . .

BLS concludes that the labor market for engineers in the rest of the decade should be the same as it was in 1980. So, if there were sporadic shortages of EEs in 1980, there should be sporadic shortages in the future.

NSF arrives at roughly the same conclusion, but by a different route. Assuming that occupational mobility into and out of engineering are equal (the first assumption) the NSF study projects a slight excess of demand over supply for electrical engineers in 1987 (2.4 to 7.9 percent vacancies), and a rough balance for the remainder of engineering fields. The second assumption leads, by definition, to a balance of supply and demand. Finally, the shortage predictions of AEA are considerably more severe, due to their use of a questionable methodology.

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[9] *Engineering Education and Practice in the United States,* op. cit., p. 57; Scientific Manpower Commission, *Manpower Comments,* January-February 1985, p. 34.

William Upthegrove presented a commentary at the NRC symposium based on a Business-Higher Education Forum study of *Engineering Manpower and Education*[10] that sheds considerable light on the issue of supply and demand balance. Figure 4-5,[11] taken from Upthegrove's presentation, shows the flow of engineers into and out of the profession. It reveals that when immigrants, bachelors of engineering technology, and B.S. degree holders from related fields such as physics and mathematics are taken into account, only one-third of the growth plus replacement demand must be filled by interfield mobility and upgrading of nonengineers. Upthegrove's flowchart does not take into account the 18,000 new engineering M.S. degree holders who enter the job market each year and are available to contribute to the supply side of the picture. With these included, the supply-demand balance would look even more favorable.

Defense Needs

Before proceeding to look at labor market adjustments to shortages, a key question that must be examined is the effect of defense budget increases on the demand for engineers. How sensitive are the projections of engineering demand to changes in defense spending?

AEA asked its respondents to identify the portion of their projected future requirements that were based on the assumption of receipt of defense contracts. The purpose of this question was to avoid the problem of double and triple counting, where several firms project the same hiring requirements based on receipt of the same defense contracts. The response to this question can be used to estimate the effect of increased defense spending. According to the responses, 16 percent of their projected requirements were based on anticipated defense contracts. Hence, even a doubling of defense spending would not have a large effect. This conclusion is buttressed by the results of Harrington, et al.'s survey which reported that "most respondents did not see increasing defense outlays as a key cause of future shortages."[12]

NSF studied the impact of different levels of defense spending in more detail, and came to roughly the same conclusion. It looked at two different levels of defense spending—the "high" projection which assumed a 45-percent increase in real defense spending between 1982 and 1987, and a "low" projection which assumed a real increase of 18 percent over the same period. The NSF study found that shifting from low to high defense spending projections increased the total demand for engineers by 85,000 in 1987. This is an increase of about 6 percent, and has the effect of turning a slight shortage into a slightly larger one.

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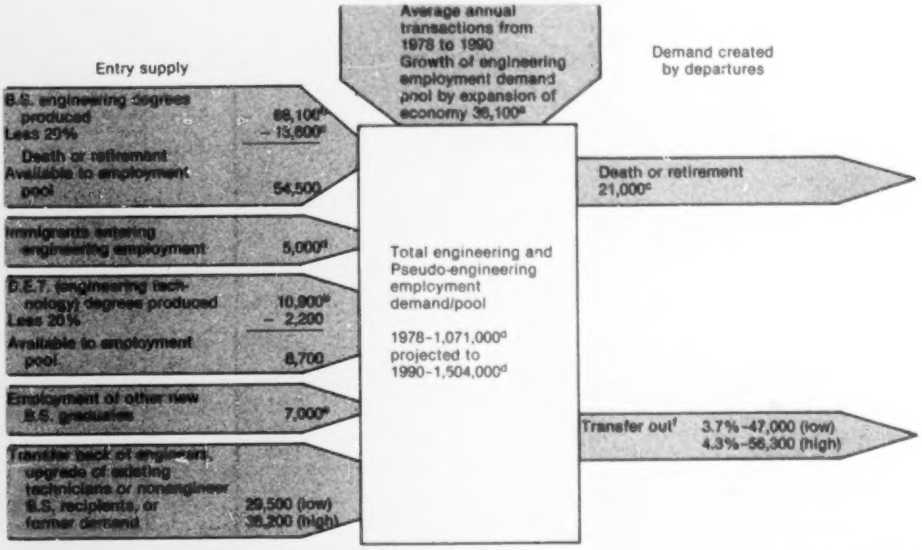
[10] Business-Higher Education Forum, "Engineering Manpower and Education—Foundation for Future Competitiveness," October 1982.

[11] *Labor Market Conditions for Engineers: Is There a Shortage?* op. cit., p. 64.

[12] Harrington, et al., op. cit.

Figure 4-5.—Supply and Demand for Engineers, 1978-90

Total supply = 104,700 to 113,400 per year.
Total demand (growth + death and retirement + transfers out)
= 104,100 - 113,400 per year.


Entry supply
B.S. engineering degrees produced 68,100[b]
Less 20% −13,600[c]
Death or retirement
Available to employment pool 54,500
Immigrants entering engineering employment 5,000[d]
E.E.T. (engineering technology) degrees produced 10,900[b]
Less 20% − 2,200
Available to employment pool 8,700
Employment of other new B.S. graduates 7,000[e]
Transfer back of engineers, upgrade of existing technicians or nonengineer B.S. recipients, or former demand 29,500 (low) 38,200 (high)
Average annual transactions from 1978 to 1990
Growth of engineering employment demand pool by expansion of economy 36,100[a]
Total engineering and Pseudo-engineering employment demand/pool
1978-1,071,000[d]
projected to
1990-1,504,000[d]
Demand created by departures
Death or retirement 21,000[c]
Transfer out[f] 3.7%-47,000 (low) 4.3%-56,300 (high)

[a] M. L. Carey (Bureau of Labor Statistics), "Occupational Employment Growth Through 1990," *Monthly Labor Review*, August 1981. These data from "low" growth projection.
[b] Averages determined from values of table 18 in National Center for Education Statistics, *Projections of Education Statistics to 1988-89* (Washington, DC: U.S. Government Printing Office, April 1980); and 1990 values from NCES Bulletin 81-406, Feb. 13, 1981.
[c] *Occupational Projections and Training Data, 1980 Edition*, Bureau of Labor Statistics, U.S. Department of Labor Bulletin 2052, September 1980. The 20% figure is probably conservative in light of the increasing enrollments of nonpermanent foreign nationals in engineering programs.
[d] BLS estimates. This estimate is consistent with W. P. Upthegrove's impression that about one-half of foreign nationals who take B.S. or M.S. degrees in U.S. engineering colleges eventually stay in the United States.
[e] Unpublished data compiled in 1978-79 by Daniel E. Hecker, Bureau of Labor Statistics.
[f] Survey of engineering employment 1974-1976 suggested an average transfer-out of 3.7%. More recent surveys have indicated an even higher rate (unpublished Bureau of Labor Statistics data from Daniel E. Hecker).

[a] M.L. Carey (Bureau of Labor Statistics), "Occupational Employment Growth Through 1990," *Monthly Labor Review*, August 1981. These data from "low" growth projections.
[b] Averages determined from values of table 18 in National Center for Education Statistics, *Projections of Education Statistics to 1988-89* (Washington, DC: U.S. Government Printing Office, April 1980); and 1900 values from NCES Bulletin 81-406, Feb. 13, 1981.
[c] *Occupational Projections and Training Data, 1980 Edition*, Bureau of Labor Statistics, U.S. Department of Labor Bulletin 2052, September 1980. The 20% figure is probably conservative in light of the increasing enrollments of nonpermanent foreign nationals in engineering programs.
[d] BLS estimates. This estimate is consistent with W.P. Upthegrove's impression that about one-half of foreign nationals who take B.S. or M.S. degress in U.S. engineering colleges eventually stay in the United States.
[e] Unpublished data compiled in 1978-79 by Daniel E. Hecker, Bureau of Labor Statistics.
[f] Survey of engineering employment 1974-1976 suggested an average transfer-out of 3.7%. More recent surveys have indicated an even higher rate (unpublished Bureau of Labor Statistics data from Daniel E. Hecker).

SOURCE: *Labor-Market Conditions for Engineers: Is There a Shortage* (Washington, DC: National Research Council, 1984), p. 64.

Thus, increased defense spending can boost engineering demand somewhat, but not enormously. This should not be surprising—only 18 percent of the Nation's engineers are employed in defense-related industries,[13] so an increase of one-fourth to one-third in defense spending (the difference between the high and low scenarios) should generate a 4- to 6-percent overall increase.

There exists a rule of thumb to calculate the effect of defense spending on the demand for engineers. According to Landis,[14] an additional $1 billion (1983$) in military spending will generate a demand for about 1,000 additional engineers if the funds are spent on procurement, and about 4,000 additional engineers if they are spent on R&D. On the average, electrical engineers should make up about one-fourth to one-half the additional demand.

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[13] *The 1982 Post Csnsal Survey of Scientists and Engineers*, NSF 84-330 (Washington, DC: National Science Foundation, 1984), p. 60.

[14] Fred Landis, "The Economics of Engineering Manpower," *Engineering Education*, December 1985.

Finally, we note that although defense spending has a relatively small effect on overall levels of engineering demand, it may have a very large effect on specialized subfields. It is impossible, however, to generalize about these localized demand effects. In the next section we will discuss what is known about supply responses to subfield shortages.

ADJUSTMENTS TO SUPPLY-DEMAND GAPS

The essential nature of a labor market is that it adjusts; supply and demand respond to the surpluses and shortages. A projected gap between supply and demand usually does not indicate an impending shortage; rather, it signals that some sort of adjustment has to take place. Two types of adjustment are possible: The first are adjustments among potential employees, such as an increase in the numbers of entry-level engineers or mobility of experienced workers into shortage occupations. The second are adjustments by employers of engineers who can:

- increase their search and recruiting efforts;
- rearrange jobs to utilize available skills, education, and experience more efficiently;
- make larger investments on internal training and retraining of engineers; and
- cut back on production or on R&D.

Under certain restrictive conditions no adjustment is possible. Most projections of shortages assume tacitly that demand and supply are independent, so that there can be no adjustment. This assumption makes sense, however, only under the following very restrictive conditions:

- demand for the final product is relatively unaffected by labor costs;
- supply is not appreciably affected by wage changes; and
- the shortage skills are unique, in that workers possessing them cannot be replaced by workers from other occupations or by new technology.

If *any* of these assumptions are violated, then a projected supply-demand gap will be closed by market adjustment. These assumptions are *very* restrictive—the latter parts of this section provide evidence to support the prevalence of adjustment.

However, there are two sectors of the engineering labor market in which it makes some sense to assume that supply and demand will not adjust. The first is the defense sector. In defense-related work, the demand for the final product is usually not heavily influenced by the cost (and thus not by the associated labor costs). Moreover, defense-related work may demand very specialized subfields that are in short supply in the short run.

Not surprisingly, the NSF surveys of shortages[15] bear out this observation. About 64 percent of firms with a high proportion of their employment in defense-related work reported shortages, compared to 33 percent overall. Thus, at least in the short run, it makes sense to project supply and demand independently for the defense sector.

The other sector in which a supply-demand gap actually reflects a shortage are startups. Consider, for example, newly formed companies in the computer industry. Since they are not yet producing a product, they are willing to accept losses in the short run in exchange for the possibility of large returns in the future. Instead of being expected to immediately make a profit, they are competing to get their product to market before their rivals. For firms such as these to cut back on hiring when wages go up would be completely self-defeating, since it would reduce the possibility of achieving profitability at any time in the future. Thus, demand for engineers, in this case, would be independent (within limits) of the wage level. Similarly, if the firm is using cutting-edge technology, the engineers skilled in this technology are likely to be limited in number and not easy to replace.

Supply Adjustments

Outside of the two sectors described above, there are usually adjustments available to narrow potential gaps between supply and demand. The most obvious response to a "shortage," at least in the medium term, is for an increased number of college students to receive training in that field.

Human capital theory predicts that students will, on the average, choose the profession that offers them the highest return on their investment in education.[16] Assuming that educational costs at any college do not vary by major, the choice of major should depend on expected wages and the ease of advancement.

It is not possible to measure ease of advancement, but one can measure wages. Over the past 10 years, the starting wage premium that a newly graduated engineer commands over the average newly graduated professional has fluctuated from a low of 7.5 percent in 1975, to a high of 21.1 percent in 1981.[17] During this period the number of engineering baccalaureates increased from 38,000 to 63,000. Since a large proportion of employers (35 percent in Massachusetts) adjust their wages upward in response to shortages,[18] the recent behavior of engineering undergraduates can be interpreted as a response to a shortage.

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[15] "Shortages Increase for Engineering Personnel in Industry," op. cit.

[16] Gary Becker, *Human Capital* (New York: National Bureau of Economic Research, 1964).

[17] Douglas Braddock, "The Job Market for Engineers," *Occupational Outlook Quarterly*, summer 1983.

[18] Harrington, et al., op. cit.

Freeman and Hansen[19] have constructed regression equations, based on data from 1949 to 1981, linking enrollments in undergraduate engineering programs to salaries in engineering jobs and in possible alternative occupations. They find that engineering enrollments are very responsive to salary changes: A 1-percent increase in real engineering salaries will, by their model, lead to a 2 to 4-percent increase in engineering enrollments.

Despite the responsiveness of college students to market signals, the supply of entry-level engineers can fail to adjust optimally to shortage problems for a number of reasons. First, universities and colleges may not have sufficient resources to meet student demands for a particular curriculum. This could happen because budget constraints or institutional rigidities prevent the university from paying high enough salaries to attract engineering faculty, or from investing in state-of-the-art equipment. Additionally, the university may have difficulty evaluating where a new technology is going and how long the needs for a particular type of training will last. Thus, the university may not want to make an investment in expensive equipment or new personnel in the face of uncertainty over future demand.

Students face much the same problem of having to judge the long-run value of choosing a particular subfield. Even if a new specialty is needed today, students may steer away until it has become better established. Or, conversely, students may react too strongly to current reports of shortages, as that is the only information available. Past student responses to announcements of "shortages" have resulted in surpluses a few years later.

In all of these cases, both educational institutions and students may be acting rationally, given the available information. However, the overall result may not be socially optimal.

Occupational Mobility

An increase in the number of engineering B.S.s in response to a wage increase is not a short-term remedy to a supply-demand gap. It takes 4 or more years to train a new engineer in college. In a fast-moving market the needs of employers will have undoubtedly changed by the time entering students graduate. This lag effect is especially powerful for occupations subject to sudden unanticipated surges in demand. The semiconductor boom of the past 10 years, for example, was largely unanticipated. How are jobs in such rapid growth areas filled?

One possibility is that people can move over to these "shortage" jobs from related fields. A large amount of independent evidence exists for such occupational mobility. An NSF study reports that 8 percent of those employed as mathematicians in 1972 had become engineers by 1978.[20] Over the same period, about 5 percent of physical scientists switched into engineering. Overall, approximately one-quarter of all scientists and engineers changed occupations between 1972 and 1978.

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[19] Richard Freeman and John Hansen, "Forecasting the Changing Market for College-Trained Workers," *Responsiveness of Training Institutions to Changing Labor Market Demands,* Robert E. Taylor, et. al. (eds.) (Columbus, OH: National Center for Research in Vocational Education, Ohio State University Press, 1983).

[20] National Science Foundation, "Occupation Mobility of Scientists of Engineers," Special Report 80-317, 1980.

Attempts have been made to create occupational mobility models on the level of detail necessary to project supply and demand. Shaw, et al., created a model in which occupational mobility was responsive to wage differences between occupations, as it should be if occupational mobility was to eliminate shortages.[21] Moreover, the magnitude of effects they found were significant relative to the size of current shortages.

The bottom line is that occupational mobility exists, it is responsive to relative demand, and it is important in reducing shortages. It is suggestive that when respondents to the 1983 AEA survey were asked how they adjusted to a shortage, almost half reported they would substitute from other specialties.[22]

The major concern about occupational mobility, from the employer's point of view, is that it may lower the quality of engineering work. This was a major theme of the 1984 NRC symposium. We do not have the direct data to evaluate this problem, but we can draw some inferences from the patterns of shortages.

First, as noted above, there have not been many reports of shortages at the entry level in recent years. Thus, any occupational mobility occurring at the entry level—e.g., college graduates who majored in physics but are taking engineering positions—has apparently not been causing serious problems. This can be explained by noting that entry-level personnel—engineers or otherwise—always have to be trained or supervised.

On the other hand, quality does seem to be a problem in hiring experienced engineers. This is reflected both in the complaints of shortages of experienced engineers, and also in the responses to direct surveys. Harrington (1983) asked survey respondents what difficulties they encountered in filling job openings for experienced EE engineers. About one-third cited wage competition as the major problem, but the remaining two-thirds of respondents pointed to "lack of occupation-specific work experience, lack of industry-specific work experience, and inadequate level of training by educational institutions" as contributing to the experienced EE shortage.[23]

Why should occupational mobility lead to more quality problems on the experienced level than on the entry level? The critical characteristic of an experienced engineer is that he or she be able to work with relatively little supervision on portions of a project. Someone switching occupations, by contrast, will inevitably need additional training and experience. It is impossible to turn a physicist into an engineer with 5 years' experience overnight, although experience in resolving problems and handling responsibilities in one field can be useful in another.

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[21] Kathryn O. Shaw, et al., *Interoccupational Mobility of Experienced Scientists and Engineers*, CPA 82-15 (Cambridge, MA: Massachusetts Institute of Technology, Center for Policy Alternatives, 1982).

[22] *Technical Employment Projects, 1983-87*, op. cit.

[23] Harrington, et al., op. cit.

The same is true when occupations are defined more narrowly. A major complaint by firms is that there is a shortage of experienced electrical engineers with expertise in particular subfields. The problem is that experienced electrical engineers specializing in other subfields have not been working for 5 years on the particular technology required by their new employer. Firms willing to hire experienced EEs without the desired skills, and then retrain them, are probably experiencing some short-term loss in productivity.

Demand Adjustments

Employers of engineers have several available responses to a potential gap between supply and demand. The most straightforward response is to cut back or slow down on research and design work to fit the available labor pool. The shortage disappears because demand for engineers is cut back.

It is hard to know how important this type of adjustment is, but cutbacks are probably the response of last resort. The AEA survey reported that only 4 percent of respondents would consider "cutting back business or reducing projects" in the face of shortages.

In a competitive economy, a firm forced to cut back on projects because of a shortage of engineers could be said to be facing the fact that there are more profitable uses for engineers in other firms. To be more precise, the present value of the expected stream of future profits from hiring this engineer is apparently higher elsewhere.

However, the U.S. economy has large noncompetitive sectors. In particular, both the defense industry and the educational sector do not base their output decisions strictly on profit motives. Moreover, not everyone in the economy shares the same expectations about the long-term usefulness of developing a new technology or product. Therefore, it is difficult to judge whether output foregone by one firm is compensated for by output increased by another firm. If shortages are severe enough, all firms may have to cut back their output.

Increased Search and Recruitment

A more common response to potential shortages is to increase search and recruitment efforts. Search and recruitment options open to employers include increased advertisements, more direct contact with colleges, use of independent recruiters, and attempts to hire experienced engineers away from other firms. The latter response may involve either offering higher wages or benefits.

According to one report, the cost of recruiting a high-tech professional (e.g., an engineer) can be as high as his or her annual salary.[24] Thus, the investment of firms in search and recruitment is not insignificant.

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[24] Tom Barocci and Paul Cournoyer, "Make or Buy: Computer Professional in a Demand-Driven Environment," Massachusetts Institute of Technology, Sloan School, October 1982.

Internal Training and Retraining of Engineers

A common response to the tight engineering market is for firms to take on more of the supply burden themselves. In Massachusetts, almost all EE employers offer tuition reimbursement plans, and half of those surveyed had formal in-house training programs for engineers.[25] According to the AEA survey, approximately 70 percent of respondents, when faced with a shortage, would try to "retrain or upgrade current employees."

Over the last few years several of the maturing computer companies, such as Data General Corp. and Digital Equipment Corp., have adopted more systematic training approaches. Faced with a continuing series of shortages, they have shifted from their traditional "buy" strategy to a "make" strategy for obtaining skilled personnel.[26] This has two major consequences. First, it helps lower the turnover rate, which, in 1979, was 35 percent for the electronics industry compared to 10 percent in basic manufacturing. Equally important, it increases the effective supply of experienced engineers. Since experienced engineers are in shorter supply than entry-level engineers, this may be crucial in alleviating shortages.

Rearrangement of Jobs

The third employer response to shortages is to rearrange jobs and tasks to better utilize the available skills. It is not clear how prevalent this response is. About 50 percent of AEA respondents would react to a shortage by "increasing productivity of currently employed engineers."

On the other hand, Massachusetts companies did not see this as a possible response to shortages. Harrington reports that "respondents did *not* see utilization of existing engineering staff as a contributing cause of shortages in the field . . . most firms are unwilling to alter their organizational structures to mitigate shortage problems."[27] These firms may feel that they have already increased productivity as much as they can so that any additional changes would be counterproductive.

Firms sometimes appear to willfully avoid organizational change which would increase profits in the face of shortages. It is important to understand, however, that some institutional rigidities which appear to block the best utilization of engineering talent may in fact be profit-maximizing in the long run. For example, the possibility of promotion into prestigious management jobs may serve as an incentive to get maximum effect out of young engineers. To keep older engineers in engineering jobs could conceivably increase the number of engineers in the short run, but it might have the effect of lowering the total amount of employee effort. Consequently, the refusal of many firms to rearrange their job structures in response to shortages is not surprising.

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[25] Harrington, et al., op. cit.

[26] Paul Cournoyer, "Mobility of Information Systems Personnel," Massachusetts Institute of Technology, Ph.D. thesis, 1983; see also Michael Mandel, "Labor Shortages in Rapidly-Growing Industries: The Case of Electrical Engineers," Harvard University, January 1984.

[27] Harrington, et al., op. cit.

THE CONSEQUENCES OF ADJUSTMENT

To see how well these adjustments to supply-demand gaps are working in the business world, OTA commissioned an in-depth interview study of the market for EEs in the Boston area. Electrical and electronic engineers were chosen because there have been repeated reports of shortages in those fields, because EEs serve both the defense and the civilian sectors, and because employers of these engineers are often producers of new high-technology growth products such as computers and electronic equipment. Interviews were conducted in the Boston area by OTA contractor Dr. W. Curtiss Priest of Massachusetts Institute of Technology (MIT).

The interviews covered 5 categories: large firms (5), small firms (4), engineering school deans and chairmen (4), university placement and employment agencies (4), the Massachusetts High Technology Council Director, and "headhunters" (2). The interviews focused on the availability of the electrical engineer in the Boston-Route 128 region.

In selecting firms, a variety of firms were chosen, reflecting the type of market (defense and civilian) and products. Also, various firms have different reputations for hiring requirements and corporate climates. The typical contact at each firm was the vice president of engineering. The firms contacted were: Raytheon Corp., AVCO Corp., Wang Laboratories, General Electric (GE), Polaroid Corp., Pacer Systems, Inc., Baird Corp., Technical Alternatives, Inc., and Apollo Computer Corp.

Engineering school deans and chairmen were contacted at MIT, Northeastern University, Tufts University, and the Franklin Institute. University placement contacts were at MIT and Northeastern. Employment agencies contacted included Computer Placement Unlimited, Inc., High Technology Placement of Winter, Wyman & Co., Fortune Personnel, and McKiernan Associates.

Nearly all of the interviews were made in person and lasted from 1 to 2 hours in length. An open-ended discussion was conducted with each contact using seven categories of questions. These questions investigated how shortages of engineers vary over the short and long term, the availability of particularly needed skills, and the ability of engineers to grow into job requirements. Additionally, the discussion covered the impact of military procurements, the benefits and environments required to attract engineers, and the sensitivity of universities to market demands. Finally, interviewees were asked to compose a "wish list" in order to identify major concerns about the availability of engineers. To explore the hiring requirements in detail, the respondent was asked to describe a job description and how closely a hire would have to match the description.

Variability in Shortages of Engineers

Each firm had a uniquely different set of experiences regarding shortages of engineers. These experiences depended on the character of the firm, its location, and its reputation. In general, industry responded that there were certainly shortages of some types of engineers at particular times but some firms reported no shortages because of their particular position in the market.

Shortages of engineers vary by *geographic location.* While the focus of the study was on the Boston-128 region, a number of firms had multiple locations across the country. Raytheon Corp. has experienced some shortages in the Boston region but extreme shortages in the Santa Barbara area. Likewise, Pacer Systems has experienced some shortages in the Boston area but more shortages at their Pennsylvania location where there is a higher demand for engineers with substantial military service experience. A number of placement respondents commented on the existence of shortages in the Silicon Valley area because of the very high costs of living.

Shortages vary by the firm's *reputation and culture.* Apollo Computer and Wang Laboratories stated that they do not suffer from any shortages of engineers. Both firms are successful computer applications firms with distinctive corporate climates and reputations. Apollo Computer has a unique reputation for fast growth and the "Apollo culture." This places the firm in an "unreal, dreamworld existence" in which they can be extremely selective about applicants. In contrast, a company like Baird, an instrumentation firm, often finds it difficult to hire engineers within salary ranges they can afford. They prefer to hire fresh graduates to help keep down salary costs.

Shortages vary *across general areas* related to electrical engineering. Electrical power generation and distribution is an area that depends on the construction market and the demand for electricity. The demand for electrical engineers in this area is fairly steady and the supply appears adequate. The electronics industry, in contrast, has had substantial periods of growth, creating a high demand for the electronics-oriented electrical engineer. There have often been periods of shortages for particular skill requirements in the electronics field. Computer programmers in electrical engineering applications areas have also been in heavy demand. However, there is some indication that 2-year educational programs are successful in meeting the demand for many of these requirements.

Shortages also vary considerably by *special skill needs.* There are certain positions that require both excellent electronics hardware skills *and* strong computer programming skills, such as in the design of the next generation of computers. Qualified people are very scarce. Another current area of shortage is in the use of automatic test equipment (ATE). Knowledge of ATE has become quite specialized to certain machines and software packages. It is difficult to locate people with the required background. Another scarce skill area involves engineers with both analog and digital hardware experience. Many older engineers skilled in analog hardware find it difficult to make the transition to digital hardware. Younger engineers, more skilled in digital work, find analog hardware difficult and foreign.

Changes in markets and opportunities are constantly producing specific skill shortages. The recent emphasis on "automatics" such as robotics and other industrial control machinery has created a heavy demand for industrial electrical engineers. Until a few years ago, industrial engineers were in low status positions and many universities, such as MIT, did not train industrial engineers. Another recent growth area, "very large-scale integrated circuits," has created shortages of engineers both in industry and universities.

Shortages vary *over time* as economic conditions and growth opportunities change. Respondents with 20 to 30 years of experience recall the ebb and flow of hiring over a number of cycles of high and low demand periods. Memories were recalled of how in the late 1960s, half of the employment agencies went out of business, and stories were circulating of engineers driving taxis. More recently, shortages in 1979 and 1980 were remembered in terms of prolonged searches and less than optimal hires. In prior decades, military employment was viewed as unstable and companies such as Polaroid were considered stable and secure. In the current decade, military employment is seen as a refuge and the frequent cycles of civilian layoffs are viewed with greater anxiety. The current softening of the market is viewed by many as a temporary adjustment period.

Shortages are not perceived to vary much by the level of *military procurements*. Many respondents emphasized that the two climates of military and civilian work are so different that there is low mobility between the two "sectors." The military engineer is viewed as more risk averse, less creative, and less likely to be interested in advancement. In contrast, the civilian engineer is viewed as more people oriented, more talented, better able to bring out products, and more selective. It is more likely that engineers will move into the military sector when civilian hiring is down than will military engineers move into the civilian sector when hiring in the military sector is down. Thus, when military procurements are rapidly increasing, those hiring in the civilian sector sense less competition in hiring the same people than they might if the mobility were higher.

Raytheon, a company with about 75 percent of its engineers conducting military work, indicated that they keep salaries at about the same level for both civilian and military positions regardless of changes in demand for military work. Pacer Systems indicated that tight government auditing practices kept them from bidding up salaries for military engineers. While some of these statements appear to defy the economic laws of supply and demand, they were prevalent enough to warrant further investigation.

Impact of Shortages

In general, shortages tend to lengthen search times and may relax, somewhat, the requirements required for a position. Many respondents stated that, for the most part, the supply of engineers had improved over the last 5 to 8 years. Even during high demand periods, the impact of shortages has not been dramatic.

Changes in the level of shortages of electrical engineers substantially affects the *search time* for a new hire. Responses about variability in search time were fairly consistent. During periods of reasonable availability the search period takes 1 to 1½ months. During periods of greater shortage, this time can easily double and a search period of 4 to 5 months would not be unusual. In these periods, lesser known firms must be prepared to settle for less desired choices in candidates. Special needs require more search time; the process of hiring the right chief engineer when the requirements are fairly unique can take more than a year.

Shortages have an impact on the *quality of engineers and productivity.* For example, during the recent 1979-80 shortage, a number of respondents said that significant compromises were made in hiring. The level of experience criterion was met less often. Also, firms used to hiring from "first rate" schools might find it necessary to relax their requirements to include other schools during high shortages. Nonetheless, there was a sense that no large departures from expectations were ever made. The compromises were significant but not highly burdensome.

Shortages also have an impact on *deferred opportunities*. For example, new hires in specific areas may add to the future research capabilities of a firm, but a shortage in that area presents an "opportunity cost" to the company's R&D effort. Polaroid encountered shortages of Ph.D. optical engineers and AVCO described shortages of "hard science" based engineers that impeded expansion of their research capabilities.

A major impact of shortages may be *job-switching and high expectations* of engineers. A "star" engineer (heavily sought after for his or her high abilities and relevant skill area) will often switch jobs every year or two. The change is typically made to receive more responsibilities, work on more challenging problems, and for the corresponding salary increase.

The electrical engineer has fairly high expectations about the job in terms of challenge, good relationships with the supervisor, promise of R&D work, freedom and independence, cutting edge projects, being entrepreneurial in design, and high salary. With a very high degree of consistency, respondents described these expectations and the importance of meeting them to hire and retain the engineer. It was also emphasized that a good salary went along with the other expectations and was not typically sought after as the primary goal.

Mobility and Flexibility of Engineers and Related Professionals

In general, it is difficult for an engineer to take a job requiring work much different than his or her previous experience. There are certain "feeder" fields like math and physics but it is nearly impossible for, say, a chemical engineer to take a position as an electrical engineer, or even for an electrical engineer experienced in radio-frequency design to take a job in computer design. Professionals in *math and physics* are often hired for "systems" work because their general training is useful in general problem-solving and design. They are more likely to be hired by firms engaged in basic research, such as Polaroid and AVCO. They are less likely to be hired by a firm like Apollo Computer. Thus, when the demand is higher for engineers than scientists, as has been the case over the last 10 years, mathematicians and physicists can shift to fill some of the demand. To illustrate the magnitude of this shift, from 1973 to 1983 the number of undergraduates in engineering at MIT (primarily electrical engineers) has gone from 1,257 to 2,405. Over the same time period, the number of undergraduates in the school of science has declined from 1,162 to 725.

Not all engineers are equally "flexible" or "mobile." The engineer in the *top quartile* of his profession is considered much more mobile and flexible than the other 75 percent in the profession. Engineers that have reached positions of management or high rank typically have greater flexibility and mobility than more junior engineers. Three factors seem to play a part in restricting the flexibility and mobility of engineers—market limitations, management restrictions, and *know-how* limitations. These factors are not independent, but work together to reduce mobility and, at the extreme, to render obsolescent many engineers.

In terms of *market limitations,* firms often change while in a period of crisis. They require particular engineering skills immediately and obtain these skills from the outside market because it is not practical to retrain in-house engineers in the time available. In terms of *management restrictions,* engineers become identified by management as having certain abilities and know-how; it is difficult for management to take the risks associated with allowing an engineer to make a transition to a new skill area.

In terms of *know-how,* engineering is a highly "know-how" intensive profession. It takes considerable training and practice to be proficient in a particular area of electrical engineering and while some of these skills are transferable, many are not. For example, analog circuitry know-how is not highly transferable to digital circuitry. Thus, over the last 20 years when the field was moving from analog to digital, many engineers became increasingly outmoded.

The interviews constantly reinforced this dynamic picture of the way many engineers become unable to face periods of transition. Many respondents spoke of the need for more engineers to "keep up." There were stories about the key engineer who did keep up and how he or she played a significant role in the newer areas, in contrast to those who did not. The placement officer at Northeastern referred to those engineers who worked in the same area for 10 to 15 years and then had to return to drafting or some other occupation requiring less skills when the area dried up. While many professional fields are faced with technological change, the engineering profession is probably more vulnerable than most.

For the more mobile and flexible engineers, the *headhunter* plays a critical and dynamic role. The employment headhunter is a placement person who actively seeks out individuals to meet a client's employment needs. Many employment agencies receive applications from engineers and match these with employment opportunities they have identified in industry. The headhunter goes one step further and attempts to lure a "star" engineer out of one company to another. As disruptive as this first appears, the headhunter plays an important role from the standpoint of economic efficiency. He or she is helping to allocate a scarce resource to a more optimal allocation. The headhunter establishes a network of contacts both within organizations looking for talent and within organizations where the talent is "misapplied" or "underutilized."

In matching individuals, the headhunter is sensitive to the flexibility of the employer in terms of the technical capabilities of the individual and the personal match. Often it was said that employers hire "people they like." Thus engineers from certain styles and cultures of firms are much more likely to fit a particular position than others. But other placement professionals warned against overemphasizing the cultural variable. The bottom line is how well the person can do the job and as monolithic as many firms appear, there are many subcultures within any given organization.

In summary, many factors play a role in restricting mobility and flexibility. These relate to both technical variables and cultural variables. For small incremental shifts in the work force, these factors will not be highly significant. For major occurrences of technological change and large changes in the economy, however, these factors will be quite important.

Desirable Changes

In concluding each interview, participants were asked to identify the most desirable changes relating to the availability of engineers. The responses addressed various availability, quality, and professional issues.

In terms of *shortages,* people in employment agencies all wished they could have a larger, more capable pool of engineers to draw from. Since they are personally responsible for how well they meet their clients' expectations, this is a significant statement about the shortage of engineers. Within industry, if a firm required a particular specialty which was in short supply, the response was to have more engineers trained in that specialty. For example, the GE generators section wished more schools provided "power systems engineers." Raytheon, involved in more radio work, wished schools trained more radio-frequency engineers. In many cases, the undersupply was in a low glamour area. Power systems engineers, industrial engineers, etc., are lower status areas and many students prefer the high tech, high glamour areas. Whether "glamour" is a "correct" economic market signal for whether students should pursue a particular area of electrical engineering is an interesting question.

This leads to a very serious issue of the status of engineers in general. Respondents from universities unanimously indicated that they were upset about the "second class" treatment of engineers. One respondent described industry as treating engineers as a commodity while another indicated that engineers are often used for "subprofessional tasks." The dean of one engineering school suggested that the supply of engineers should be limited, as the medical profession has done with doctors, so that the standards of professional excellence and stature could be raised. The German model was considered a success in maintaining engineering professional standards. There may be a linkage between the status issue and the factors that lead to immobility and inflexibility discussed above. How can an engineer be a professional if so much of his or her know-how can be be made obsolete by the advancement of technology? One response to this dilemma has been to institute "lifelong learning."

Lifelong learning was emphasized by both respondents in industry and in the universities. A recent conference on "Keeping Pace With Change: The Challenge for Engineers" was sponsored by the Massachusetts High Technology Council and held at Northeastern University. In a study sponsored by the High Tech Council, the "half-life" of the engineering degree (length of time half of the knowledge acquired by graduation remains relevant to work tasks) was estimated to be between 3 and 5 years for the Bachelor of Science in Electrical Engineering. The peak age for the performance of engineers, in terms of age, was found to be the late twenties and early thirties. According to this study, productivity typically declines from age 30 until retirement.

To counteract this process, lifelong learning programs have been established within industries and through universities. It was noted that the engineer over age 35 cannot be expected to return to the classroom but needs different educational resources to keep up. The older engineer needs support groups in the company of his peers. One program is provided by Northeastern University where live graduate courses are provided using video to locations along Route 128 in Boston. The system has two-way voice for communication and courier service for homework.

Perhaps, too, with newer information technologies, the engineer can keep pace by greater use of information databases where the knowledge is keyed *by function and application*. While general citation databases exist such as COMPENDEX on Dialog Information Services, these only provide bibliographic citations to the engineering literature—a literature which is itself surprisingly *low* on useful material. If the private market cannot respond in providing these information services, it may be a role of government to help meet this need.

Respondents also expressed the wish for engineers to have additional skills beyond basic engineering capabilities. A few respondents emphasized the need for engineers to be better able to communicate and write. A few indicated the need for engineers to be better able to use computer simulation to test a prototype design in place of building the prototype because of the high costs involved in making custom integrated circuits. Two respondents emphasized the need for engineers to have stronger skills in scheduling and planning, and a better sense of management's objectives.

Finally, Polaroid, AVCO, and Raytheon indicated the need for government and industry to provide greater support of hard science and applied research. A vice president at AVCO was highly concerned about the loss of hard science Ph.D.s since the Vietnam War who could not only contribute to military strength but to basic research vital to civilian industrial strength. From the university side, Tufts noted that the current NSF emphasis on large research programs has greatly reduced opportunities to support research at Tufts. The Commonwealth of Massachusetts' program to provide research facilities in microelectronics available to universities and industry was lauded as a way of providing facilities that Tufts could use to educate their engineering students.

CONCLUSION

Shortages exist for engineers, especially for those in a few high demand fields. In the last 5 to 8 years, however, shortages have been troublesome but not a large burden. Some firms have never perceived shortages while others find the supply of engineers much too small. The flexibility and mobility of some engineers is high but for most engineers it is low. The engineering market performs reasonably well for gradual transitions but does not perform well during periods of major technological change or dramatic changes in market and/or economic conditions.

In general, there does not appear to be a need for a direct government role in alleviating potential shortages of engineers. The market for entry-level engineers seems to be functioning well enough now to eliminate shortages. At the bachelor's level, some educational institutions report that they do not have enough resources to train all the engineers that are interested, due to shortages of faculty and equipment.

Although there have been, and will continue to be, spot shortages of experienced engineers, they are not of a type amenable to direct government intervention. When a new technology is developed, it simply takes time before there is a pool of engineers who are experienced with the new techniques. There may be a role for the government in helping to promote the retraining of experienced engineers into startup fields. Mission-agency sponsored R&D programs could conceivably serve that retraining function. The Federal energy and environment programs of the 1970s, for example, helped retrain significant numbers of scientists and engineers to become specialists in those two fields. Many of these people are currently employed in their new capacity by industry.

A fundamental problem is the obsolescence of *know-how* and the corresponding obsolescence of engineers. In response, many institutions and firms are encouraging lifelong learning. Since government has traditionally played an important role in education, there are some policy options which may help. One important role is to provide basic facilities for education such as the microelectronic center that Tufts and other universities find important in helping train engineers. Another role is to identify economic disincentives to lifelong learning and provide either educational support or tax relief to enable more engineers to keep up their know-how.

In the area of information policy, there is the question of how new information technology can assist in providing ongoing know-how support and lifelong learning to engineers. Does the structure of the market of engineers and their employers encourage the private sector development of such information support systems, or are there public sector reasons for government support? A number of market failure reasons can exist for the lack of the development of such support systems. To the extent that firms do not fully bear the costs of the obsolete engineer, firms will underinvest in further training, etc. Also, information has transferability problems—it is often difficult for the supplier to exact the full value of the information because it is difficult to keep the information from being passed along (with no further revenue to its producer).[28]

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[28] For a comprehensive discussion of these and other reasons see W. Curtiss Priest, "The Character of Information," contractor paper for U.S. Congress, Office of Technology Assessment, Project on Intellectual Property, Feb. 10, 1985.

Chapter 5: Demographics and Equality of Opportunity

The principle of equality of opportunity in scientific and engineering careers is embodied in the Equality of Opportunities in Science and Technology Act of 1981:[1]

> The Congress declares it is the policy of the United States to encourage men and women, equally, of all ethnic, racial and economic backgrounds to acquire skills in science and mathematics, to have equal opportunity in education, training, and employment in scientific and technical fields, and thereby to promote scientific literacy and the full use of the human resources of the Nation in science and technology. To this end, the Congress declares that the highest quality science over the long-term requires substantial support, from currently available research and educational funds, for increased participation in science and technology by women and minorities.

The Act sets out three reasons for promoting equality of opportunity: equity, the need for general scientific literacy, and the desire to fully utilize all human resources that could be applied to science and technology. It also explicitly calls for the commitment of Federal resources, within the overall scientific research and training budget, to programs which promote increased participation by minorities and women in science and technology. This commitment has not been completely carried out.

The changing college student demographics of the coming decade have several important implications for national policy regarding equality of opportunity. If the number of college graduates declines substantially, as predicted, the principal of utilization of all potential human resources to the fullest extent possible will become especially important. Although, as argued in chapter 1, it cannot be proven conclusively that the Nation requires the current level of 300,000 new science and engineering bachelor's degree recipients per year, it would not appear prudent, in an era when science and technology are expected by many to play an increasing role in improving our economic competitiveness and national security, to allow the number to decline appreciably. Therefore, from a "utilization of resources" point of view, programs to promote participation of historically disadvantaged groups take on greater significance.

The increasing fraction of college students who are likely to be drawn from the black and Hispanic populations, that have historically participated in science and engineering education and employment at far lower rates than the white population, imply that programs directed at these two minority groups may be needed to keep the supply of scientists and engineers from declining.

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[1] National Science Foundation Authorization Act of 1981: Public Law 96-516, Section 32(b).

In order to understand what will be required, it is important first to have a clear picture of the factors leading to reduced participation by women and certain minority groups in science and engineering. These factors are complex, interrelated, and span the full developmental cycle from early childhood socialization to experiences in the work force. They include:

- the continuing legacy of decades of discrimination and discouragement from scientific and engineering careers,
- differential treatment of women and minorities in the science and engineering work force,
- lack of early educational opportunities due to social class and cultural factors among minorities,
- female socialization patterns that discourage young women from perceived "masculine" careers,
- expectations that women will continue to assume the major role in housekeeping and childrearing and sacrifice their professional interests to those of their husband,
- lack of financial support and institutional biases in the higher education system, and
- lack of role models and early exposure to science and engineering as worthwhile and accessible careers.

The sections that follow will review, briefly, the participation rates in science and engineering education and employment for both women and minorities, and discuss in some detail the principal causes, as currently understood, of those low participation rates. The limited evidence on the effectiveness of intervention programs that have been initiated to increase participation in science and engineering among these groups will be presented. Finally, a set of policy and research issues related to increasing the participation of women and minorities in science and engineering will be given. These issues have been identified by a review of the literature, an OTA workshop, and a questionnaire to practitioners in the field.

WOMEN

The increasing participation of women in scientific and engineering education and employment is a well-documented phenomenon. The trend is most dramatic in higher education, where women's share of total science and engineering baccalaureates increased from 28 to 36 percent; of master's degrees from 18 to 28 percent; and of doctorates from 15.5 to 29.4 percent between 1972 and 1982. Figure 5-1[2] illustrates that increasing participation by field and degree. In employment the trend is less dramatic but still significant. Women constituted 8 percent of the Nation's scientific and engineering work force in 1973; a decade later they were 13.1 percent. The most impressive gains were in computer specialists, engineers, and life scientists, where the numbers of women increased by factors of 4, 3, and 2 respectively between 1976 and 1983.[3]

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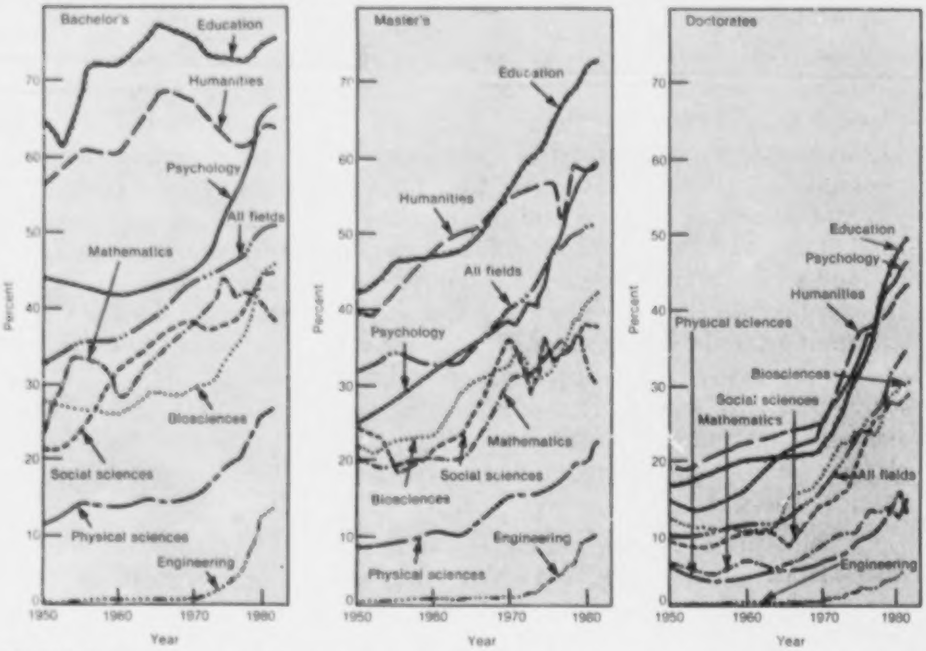
[2] Betty M. Vetter and Eleanor L. Babco, *Professional Women and Minorities*, 5th ed. (Washington, DC: Scientific Manpower Commission, August 1984), p. 37.

[3] *Science and Engineering Personnel: A National Overview*, NSF 85-302 (Washington, DC: National Science Foundation, 1985), pp. 53-54.

Figure 5-1.—Percent of Degrees Granted to Women 1950-82



SOURCE: Scientific Manpower Commission, *Professional Women and Minorities* (Washington, DC: 1984), p. 36.

Two issues link women's increasing participation in science and engineering to the demographic trends which are the subject of this technical memorandum:

1. the degree to which the increasing participation of women in science and engineering is likely to continue over the next two decades, and
2. the implications of overall demographic trends for policies and programs to promote equality of opportunity for women in science and engineering.

To understand these issues better, it is necessary to examine the factors that influence women's decisions to enter and remain in science and engineering careers.

The Science and Engineering "Pipeline"

According to Sue Berryman, the pool of talent from which the Nation's scientists and engineers is drawn is largely formed in high school. Interest in science and mathematics first appears in elementary school, develops most intensely prior to 9th grade, and basically is completed by the 12th grade. After high school, migration is almost entirely out of, not into, the pool. As a consequence:

> . . . those who obtain quantitative doctorates or have mathematically-oriented careers a decade after high school come overwhelmingly from the group in grade 12 who had scientific and mathematical career interests and high mathematical achievement scores . . . . By grade 12, these achievement scores clearly differentiate those who plan [to attend] college from those who do not and

those who plan quantitative college majors from those who plan non-quantitative ones.[4]

If we follow a group of 4,000 seventh graders —half boys and half girls— through the sequence of steps from age 12 through 32 that ultimately select those who will become scientists and engineers in quantitative fields (the physical sciences, mathematical and computer sciences, biological sciences, economics and engineering), we find the following interesting patterns.[5] About half each of the boys and girls will have taken and understood enough mathematics by age 12 to be capable of pursuing sufficient advanced work in high school to prepare for a quantitative major in college. (At age 12 the mathematical abilities of boys and girls are almost identical.) Of this group of 1,000 boys and an equal number of girls, only 280 boys and 220 girls will actually take enough high school mathematics to major in a quantitative field in college. This difference in numbers of students taking advanced mathematics courses is one of the factors leading to the observed differences between young men and young women in college SAT mathematics scores.

Of the original 2,000 young potential scientists and engineers, only 140 of the boys and 45 of the girls will actually enter college with plans to major in science or engineering. Forty-five of those young men will emerge from college with a quantitative baccalaureate degree; 20 of the women will do likewise. At the Ph.D. level, five men and one woman, of the original science and engineering pool of 2,000, will actually receive a doctorate in a quantitative field.

We can see from the above statistics just where women's participation in quantitative fields drops off most sharply. Between the age of 12 and the selection of a potential major in college at age 18, young women's persistence in the science and engineering "talent pool" falls off three times as rapidly as that of young men. After college, 1 out of every 20 women, as opposed to 1 out of every 9 men, who receive quantitative B.A.s goes on to complete a quantitative Ph.D. Thus, it is at the pre-college and postgraduate levels that we should look for factors that discourage women from pursuing science and engineering careers.

The factors that lead college freshmen women to pursue science and engineering majors less frequently than men are best illustrated by a comparison of major field preferences among college freshmen. The 1984 study of *The American Freshman* by the Higher Education Research Institute[6] shows exactly where the two sexes differ most in their preferences. Twenty percent of the men, but only 3 percent of the women, report an intention to major in engineering. Three and one-third percent of the men, but only 2 percent of the women report an intention to major in a physical science.

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[4] Sue E. Berryman, *Who Will Do Science* (New York: The Rockefeller Foundation, November 1983), pp. 66-77.

[5] Betty M. Vetter, "The Science and Engineering Talent Pool" in Scientific Manpower Commission, *Proceedings of the 1984 Joint Meeting of the Scientific Manpower Commission and the Engineering Manpower Commission* (Washington, DC: National Academy of Sciences, May 1984), pp. 3 and 5.

[6] Alexander W. Astin, et al., *The American Freshman: National Norms for Fall 1984* (Los Angeles, CA: The Cooperative Institutional Research Institute, University of California at Los Angeles, December 1984), pp. 16-18, 32-34.

By contrast, women show significantly *greater* preference for the social and the biological sciences; 8.4 to 5.1 percent in the social sciences; 4.5 to 4.1 percent in the biological sciences.

These differences are often explained as consequences of young women's lack of exposure to, or poorer performance in high school mathematics. However, *The American Freshman* survey and the records of earned baccalaureates cast considerable doubt on this explanation. According to the survey, 0.9 percent of the freshmen women and 0.8 percent of the freshmen men surveyed in 1984 intended to major in mathematics. More than 7 percent of the women and only 5.7 percent of the men intended to specialize in accounting. Twenty-five percent of the men and 23 percent of the women intended to major in a business field other than "secretarial studies." According to the Scientific Manpower Commission,[7] more than 40 percent of the bachelor's degrees in mathematics have been received by women every year since 1974. Close to 40 percent of the business and management degrees and close to 35 percent of the computer science degrees were awarded to women in 1982. Thus, it does not appear that women are avoiding quantitative fields in general due to perceived inadequacies in their mathematical capabilities. Rather, it appears that women are avoiding engineering in particular—despite significant increases in their enrollment in that field in recent years—and, to a lesser degree, physics.

To understand why women tend to select engineering as a college major so much less frequently than men do, it is useful to examine those fields which women tend to choose *far more often* than men. The fields with the largest differentials in favor of women in *The American Freshman* are: education (9.6 percent of the women, 2.8 percent of the men); nursing (7.6 percent of the women, 0.3 percent of the men); and therapy (3.4 percent of the women, 0.8 percent of the men). Those three fields account for 20.6 percent of the women and 3.9 percent of the men in the survey, a mirror image of the ratio in engineering (3.0 percent of the women, 20.1 percent of the men).

Education, nursing, and therapy are all traditional "women's fields," while engineering is traditionally a "man's field." Education, nursing, and therapy are all considered to be "helping" and "people-oriented" professions, whereas engineering is associated with building things and controlling the physical universe. Freshmen women's tendency to select the first three fields over engineering may simply indicate that traditional sex-role stereotypes and career patterns have not yet worked their way out of the system.

This should hardly be surprising from a historical point of view. It is less than a decade and a half since the women's movement forced open the doors to the traditionally male professions. All of the parents and most of the teachers of the current crop of freshmen were raised in the pre-feminist era. There are significant groups and leaders in the country who are not fully committed to the ideals of equality between the sexes in the work force. Thus, the influential adults who help to shape teenagers' ideas about the world and their place in it are not uniformly aligned in favor of efforts to break with traditional sex roles and occupational choices. The persistence of a sizable fraction of college freshmen who remain true to earlier stereotypes of "women's" and "men's" work in these circumstances is hardly surprising.

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[7] Vetter and Babco, op. cit., p. 37.

Recent research by Gail Thomas tends to confirm the persistence of traditional sex-role stereotypes. Thomas found, from an extended study of "Determinants and Motivations Underlying the College Major Choice of Race and Sex Groups," that the "choice of a college major entails a fairly predictable process that is largely formalized prior to college" and is "characterized by distinct (and to a great extent traditional) male and female interests, values, and aspirations held during childhood." These findings, according to Thomas, "imply the importance of traditional sex socialization. . . ."[8]

Sue Berryman finds an additional career-related factor helping to explain young women's decisions to avoid quantitative majors in college. The greater a woman's expectation to assume the major child rearing responsibilities of her children, the less likely she is to choose quantitative occupations that require major educational and labor force commitments. The more she expects continuous labor force participation during adulthood, the more her occupational goals approximate those of young men. Berryman notes that "studies show that male single parents make occupational and labor force adaptations to parenting that are similar to the plans of young women who expect dual family and work responsibilities."[9]

Berryman sees young women's career expectations interacting with their decision to take advanced mathematics courses to produce the pattern of underrepresentation of women in quantitative fields. "Gender differences in grade 12 mathematics achievement are primarily attributable to differences in boys' and girls' participation in elective mathematics during the 4 years in senior high school," according to Berryman. Prior to grade 9, boys and girls do not differ significantly in average mathematical achievement. The individual's confidence in his or her mathematics ability, and perception of the utility mathematics will play in achieving educational and career goals, are factors contributing to the participation in the high school mathematics sequence. The stronger the two factors are, the greater the likelihood of partipation. Since career goals seem to determine educational investments, gender differences in occupational expectations become key to understanding gender differences in high school mathematics participation. Berryman sums up by stating: **"the key for women seems to be their career choices, their investment in the junior and senior high school mathematics and science sequences being related to these choices" (emphasis added).**[10]

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[8] Gail E. Thomas, *Determinants and Motivations Underlying the College Major Choice of Race and Sex Groups* (Baltimore, MD: Center for Social Organizations of Schools, Johns Hopkins University, March 1983), p. 40.

[9] Sue E. Berryman, "Minorities and Women in Mathematics and Science: Who Chooses These Fields and Why?" presented at the 1985 annual meetings of the American Association for the Advancement of Science in Los Angeles, CA, May 1985, p. 14.

[10] Ibid., pp. 13-14.

Although Berryman sees mathematics ability and achievement as crucial to success in a quantitative career ("high mathematical achievement at grade 12 predicts realization of grade 12 quantitative career plans by age 29"), she sees such achievement as strongly related to, and influenced by, career choices already being formed in high school.

Once in college, it appears that young women have significantly *less* trouble than young men completing a quantitative baccalaureate. Forty-two percent of the women, as opposed to 30 percent of the men, who begin college with a quantitative major emerge after 4 years with a quantitative B.A. In graduate school, however, further attrition occurs. Women receive less than one-third as may quantitative master's degrees and one-fifth as many Ph.D.s. As a fraction of quantitative B.A.s women's attainment of quantitative M.A.s and Ph.D.s is less than half that of men.

The causes of women's attrition from the science and engineering "talent pool" in graduate school are not well documented. The problem does not appear to be with initial enrollment. The percentage of science and engineering graduate students who are women is almost identical to the percentage of science and engineering B.A.s awarded to women. There are some differences from field to field, with a considerable underrepresentation of women in mathematics and a significant overrepresentation in life science graduate programs, but overall the numbers are quite close, as can be seen below:[11]

Field	*Percent B.A., women, 1980-82*	*Percent grad. enroll., women, 1982*
Total, S/E	36.6%	35.3%
Physical sciences	24.5	21.0
Engineering	11.0	10.9
Mathematical sciences	36.9	27.1
Life sciences	40.0	52.4
Social sciences	51.8	47.0

The problem appears to be with persistence in graduate school, with women's participation decreasing "at each successive degree level."[12] Shirley Malcom cites one possible cause of this decline—lack of financial support:[13]

> In the 1981 *Summary Report of Doctorate Recipients*, a discussion of differences in financial support of doctoral training is a cause for serious concern. Women were more likely to report "self" sources of support. This was the primary source of support for 45 percent of the women but only 30 percent of the men. On the other hand, research assistantships were reported as the primary source of support for the doctorate by over twice as many men (22 percent) as women (10 percent).

Since research assistantships facilitate entry into a research career, by providing access to equipment, mentors, conferences, and publications, the differential access to research assistant support appears to be an especially important problem.

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[11] Vetter and Babco, op. cit., pp. 27-37.

[12] Shirley M. Malcom, *Women in Science and Engineering: An Overview*, prepared for the National Academy of Sciences (Washington, DC: American Association for the Advancement of Science, September 1983), pp. 27 and 37.

[13] Ibid., p. 8.

A second factor, however, is undoubtedly women graduate students' increasingly negative perceptions of the actual benefits their advanced degree training will bring them. Once in graduate school, women can often see in the behaviors of their professors the forms of discrimination they will face in the workplace, reducing considerably the return on their investment in higher education.

Differential Treatment of Women in the Science and Engineering Work Force

It would be nice to report that once a woman has gone through the time and trouble to receive training in a science or engineering field, especially to the Ph.D. level, she is safely ensconced in the technical work force with as great a likelihood of remaining there and receiving the full benefits of her education as her male counterpart. Unfortunately that is not the case. Sue Berryman finds that "labor force attrition rates differ far more by gender than by race" with female attrition rates "more than 50 percent higher than those of men." In 1982, almost 25 percent of the women trained as scientists and engineers, compared to 16 percent of the men, were not using their training in the scientific and engineering labor force. One-third of the women who were out of the labor force in 1982 had left for reasons of family responsibilities.[14]

Lilli Hornig, in an article entitled "Women in Science and Engineering: Why So Few?" speaks of a "gender gap in jobs" for women Ph.D.s in the science and engineering work force. With the exception of engineering, male scientists are able to realize their plans for either employment or postdoctoral fellowships sooner than women. In academia, men are "far more likely than women to be hired to tenure-track positions, to be promoted to tenure and to achieve full professorships." Women, on the other hand, "hold assistant professorships and nonfaculty positions more than twice as often as men. In industrial research, women Ph.D.s are underrepresented by about 50 percent." Those who do obtain employment are only about half as likely as men to advance to management positions.[15]

The salary differential between women and men in comparable scientific positions is quite pronounced. Data from the National Science Foundation (NSF) show that women earn less than men in almost every field of science, in every employment sector, and at every level of experience.[16] In 1982 the median annual salary of women scientists and engineers was 75 percent of that of their male counterparts: $26,300 v. $35,000. The percentage was highest among the computer specialists at 86 percent, and lowest among the life scientists, social scientists, and physical scientists at 74 percent. (See table 5-1.) Employed female scientists and engineers with less than

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[14] Berryman, 1985, op. cit., p. 7.

[15] Lilli S. Hornig, "Women in Science and Engineering: Why So Few?" *Technology Review*, November-December 1984, p. 40.

[16] *The 1982 Postcensal Survey of Scientists and Engineers*, NSF 84-330 (Washington, DC: National Science Foundation, 1984), tables B-32 and B-33, pp. 144-151; and *Science and Engineering Personnel: A National Overview*, op. cit., table B-17, pp. 128-129. These two publications are the sources for all the numbers in this paragraph. They are not quite consistent with one another.

Table 5-1.—Average Annual Salaries of Scientists and Engineers by Field and Sex/Race/Ethnic Group, 1982

Field	Total	Men	Women	White	Black	Asian	Native American	Hispanic
Total, all fields	$34,000	$35,000	$26,300	$34,100	$29,900	$34,200	$34,000	$31,400
Total scientists	31,700	33,400	25,800	31,800	28,500	32,400	32,600	27,600
Physical scientists	34,700	35,500	26,400	34,900	30,100	32,500	42,500	33,600
Chemists	33,600	34,600	25,500	33,900	29,500	30,400	42,300	29,800
Physicists/astronomers	37,900	38,100	32,600	37,900	34,600	40,500	43,500	40,500
Other physical scientists	35,000	35,700	26,300	34,900	33,400	37,100	42,100	39,800
Mathematical scientists	34,800	37,500	29,100	35,000	31,600	34,500	31,200	25,400
Mathematicians	35,400	37,700	29,500	35,600	31,800	36,200	31,200	30,000
Statisticians	32,800	36,700	28,100	33,000	30,900	28,600	(1)	17,200
Computer specialists	32,200	33,500	28,800	32,300	31,100	32,000	33,000	30,600
Environmental scientists	36,800	38,000	29,900	36,700	30,700	37,200	46,600	38,500
Earth scientists	37,600	39,000	30,300	37,500	31,200	38,100	42,200	39,800
Oceanographers	34,600	36,500	22,300	33,400	28,200	30,000	56,400	22,400
Atmospheric scientists	32,700	33,100	28,500	32,600	29,400	33,600	(1)	31,400
Life scientists	28,900	30,400	22,500	29,000	27,700	28,100	30,800	25,600
Biological scientists	28,200	29,500	22,500	28,300	28,000	27,400	25,800	24,100
Agricultural scientists	27,500	28,800	17,900	27,400	26,300	28,100	35,700	27,600
Medical scientists	38,900	42,600	28,200	39,300	27,100	32,000	34,500	30,700
Psychologists	28,800	31,700	23,900	29,000	25,900	28,400	23,300	20,400
Social scientists	30,600	33,000	24,300	30.700	26,400	34,300	29,000	24,100
Economists	34,700	35,900	29,600	34,700	31,100	37,200	28,700	31,000
Sociologists/anthropologists	24,900	27,000	21,600	24,900	23,800	26,700	28,500	18,100
Total engineers	$35,800	$36,000	$29,000	$35,900	$31,700	$35,100	$35,000	$33,700

SOURCE: National Science Foundation, *Science and Engineering Personnel: A National Overview*, NSF 85-302, p. 138.

5 years' experience earned on the average 90 percent as much as their male counterparts; those with 31 to 35 years experience earned less than 78 percent.

Aline Quester, in an exhaustive study of "The Utilization of Men and Women in Science and Engineering Occupations: Task and Earning Comparability" finds that:[17]

> Male scientists and engineers earn substantially more than female scientists and engineers. While one-fourth to one-third of the male earnings premium is accounted for by differences in income-producing characteristics between males and females (primarily different subfield concentrations), the other portion of the differential is unexplained; the men simply earn more than the women.
>
> No observable variables have yet been isolated which would account for the systematic earnings differential. If no such variables emerge in the face of repeated investigation, the presumption grows stronger that the earnings differential rests on covert discrimination.

Unemployment

In 1974, NSF reported unemployment rates [among all scientists and engineers] of 1.6 percent for men and 4.1 percent for women. By 1982, unemployment rates had climbed to 1.9 percent for men and 4.5 percent for women. Unemployment rates for **doctoral** men and women scientists and engineers were 0.9 and 3.9 percent, respectively, in 1973, and 0.8 and 2.6 percent in 1983.

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[17] Aline O. Quester, *Utilization of Men and Women in Science and Engineering Occupations: Task and Earning Comparability* (Alexandria, VA: The Public Research Institute, July 1984).

NSF found the smallest unemployment rate differential between women and men among computer specialists, while the greatest difference was noted among social scientists. After controlling for field, the unemployment rate for women remained twice that for men. For recent (1980 and 1981) science and engineering graduates at the bachelor's level, 7.7 percent of the women and 5.1 percent of the men were unemployed. Among recent master's degree graduates, 7.3 percent of the women and 2.3 percent of the men were also unemployed.[18]

Underemployment

The term "underemployment" is used by NSF to describe the combined effect of involuntary employment outside of science and engineering and involuntary part-time employment where full-time employment is sought. The "underemployment" rate for women scientists and engineers in 1982 was 5 percent; for men it was 1 percent. Part of this difference was due to the greater concentration of men in engineering, where full-time employment is more the rule. But when only scientists are compared, women are still twice as likely as men to be "underemployed." NSF reports that underemployment rates for women are higher in every field of science except for computer specialists, where the rates are essentially equal. This is true also at the doctoral level, where underemployment rates for women are above those for men in all major fields of science and engineering.[19]

Rank and Tenure

According to Betty Vetter:[20]

> Among all academically employed doctoral scientists and engineers in 1983, 65.6 percent of the men, but only 39.2 percent of the women, were tenured. An additional 14 percent of men and 21 percent of women were on the tenure track, while 8.4 percent of men and 19.9 percent of women were neither tenured nor in tenure-track positions. . . .

The National Research Council (NRC), in 1981, reported on the results of a survey of *Career Outcomes in a Matched Sample of Men and Women Ph.Ds.* It found that for men and women with degrees in the same field, in the same year, from equally prestigious universities, significant gender differences could be found in employment, rank and promotion, and salary. Specifically, NRC found that:[21]

> Among the academically employed Ph.D.s who were surveyed 20 or more years past the doctorate, 87 percent of the men were full professors compared with 64 percent of the women.

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[18] *Women and Minorities in Science and Engineering* (Washington, DC: National Science Foundation, January 1984), pp. 18-21.

[19] Ibid.

[20] Betty M. Vetter, "Women in Science and Engineering," typescript, p. 10.

[21] Nancy C. Ahern and Elizabeth L. Scott, *Career Outcomes in a Matched Sample of Men and Women Ph.D.s—An Analytical Report* (Washington, DC: National Academy Press, 1981), pp. xvii, xviii.

> For a given pair of one woman and one man with matched characteristics [10-19 years past the Ph.D.], the man is 50 percent more likely than the woman to have been promoted to full professor.
>
> Among 1970-1974 Ph.D.s one-third of the women, but one-half of the men held senior faculty posts. In every field, the distribution by rank was less favorable for women than men, based on their greater concentration among assistant professors and nonfaculty appointees.
>
> Female salaries at major research universities are significantly below the estimated salaries for men with similar characteristics.
>
> Salary differences between young male and female Ph.D.s in academe still exist, even after controlling for type and quality of doctoral training.

Lilli Hornig reports that only 79 out of approximately 4,200 faculty positions in the 171 Ph.D.-granting physics departments in the United States are held by women. Women hold only 188 of the 4,400 faculty positions in chemistry departments that grant the doctorate.[22] This situation exists despite the fact that, according to NRC, there are more than 3,600 women doctoral chemists in the U.S. labor force.[23] Vivian Gornick, in her book on *Women in Science* likens the situation of women in chemistry to that of "Jews in Czarist Russia."[24] She reports the following statement from an anonymous woman chemist at a "great research university":[25]

> The chemistry department here doesn't advertise. It's illegal now, but they still do it that way. Somehow they consider it a "shame" to advertise. They write to their friends. And of course their friends are men who have only male graduate students. But even so, some awfully good young women get through the system and come up here for interviews. It's always the same. They look at these excellent young women and they say, "She's very good but she lacks seasoning. Let her go off somewhere else for the year and then we'll consider her again." Of the young men just like her they say, "We'd better grab him before someone else does."

Implications for Women's Participation in Science and Engineering

Of the many factors that reduce the participation of women in science and engineering education and employment, the discriminatory practices discussed in the preceding section are perceived by many to be the most serious impediments to the goal of equality of opportunity. Those practices are thought to violate the equity principle most directly, because they affect people who have established, by virtue of obtaining an advanced degree, the right to pursue a scientific career based solely on the quality of their work. Their effect on women who have made the long and arduous investment in training for a scientific career can be devastating. Vivian Gornick describes discrimination against women in science as:

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[22] Hornig, op. cit., p. 41.

[23] Betty D. Maxfield and Mary Belisle, *Science, Engineering, and Humanities Doctorates in the United States: 1983 Profile* (Washington, DC: National Academy Press, 1985), p. 28.

[24] Vivian Gornick, *Women in Science* (New York: Simon & Schuster, 1981), p. 98.

[25] Ibid., pp. 102-103.

> . . . the kind of experience that becomes lodged in the psyche: both the individual one and the collective one. It may go unrecorded in the intellect but it is being registered in the nerve and in the spirit. **It means sustaining a faint but continuous humiliation that, like low-grade infection, is cumulative in its power and disintegrating in its ultimate effect** [emphasis added].[26]

The differential treatment of women in the science and engineering work force is believed to have a significant effect on female students in the educational "pipeline." A woman student in a physics or chemistry department where no women have achieved tenure, or, perhaps, even been hired to a tenure-track position, is not likely to form a positive picture of her likely future employment prospects. Nor will she experience the kind of role model which the literature on equality of opportunity suggests is desirable to assist a young woman in identifying herself with her future profession. These two factors will considerably decrease the motivation for such a student to make the sacrifices required to stay in graduate school and complete her Ph.D.

Finally, the discrimination, higher attrition rates, greater unemployment, and underemployment experienced by women as compared to men in science and engineering are seen by many to be a serious waste of human resources that have been cultivated and prepared at considerable expense to the individual and the Nation.

The two avenues for dealing with this problem appear to be strict enforcement of existing affirmative action laws, and leadership from within the scientific community. As Lilli Hornig writes:[27]

> Despite the widespread nonenforcement of "affirmative action," laws against explicit bias have opened up much broader access to education and careers for women. Universities discourage most of the more obvious forms of discrimination against woman and point with pride to equal access and success for women students . . . . The most effective way to deal with [less explicit disparities] is probably not by external intervention but through the leadership of administrators and senior faculty. MIT took this approach more than a decade ago and has had considerable success in recruiting women as both students and faculty, even in fields that have traditionally "had no women."

The National Academy of Engineering, in its report on *Engineering Education and Practice in the United States*,[28] has taken such a leadership role. It finds "anecdotal" evidence that "female engineering professors are not obtaining tenure at the same rate as their male counterparts" and "a perception of discrimination against female faculty members in assignment of teaching responsibilities and in selection for research teams." It recommends that college administrators "make a candid assessment of the negative aspects of campus life for women faculty members" and, where these are found, "take firm steps to eliminate them."

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[26] Ibid., p. 74.

[27] Hornig, op. cit, p. 41.

[28] National Research Council, *Engineering Education and Practice in the United States—Foundations of Our Techno-Economic Future* (Washington, DC: National Academy Press, 1985), p. 94.

MINORITIES

Minorities represented 9.7 percent of the science and engineering work force in 1982, up from about 5.5 percent in 1976, but substantially less than their 18.0 percent representation in the general working population. Blacks constituted 2.6 percent of the Nation's scientists and engineers, as compared to 10.4 percent of the general labor force. Hispanics represented 2.2 percent of the scientific and engineering work force, as opposed to 5.5 percent of the total labor force. On the other side of the coin, Asian-Americans' 4.5-percent share of the scientific work force was nearly triple their 1.6-percent share of the working population in the United States.[29]

In the educational "pipeline," minorities' differential experience in science and engineering from that of white males is also quite dramatic. As table 5-2[30] shows, blacks, Hispanics, and American Indians receive degrees in quantitative fields at less than half the rate of whites, while the rates for Asian-Americans are more than double that of the white population. The numbers in the table represent the ratio of the percent of quantitative degrees awarded to the particular group to its percentage representation in the age-relevant population. For example, blacks received 4.1 percent of the quantitative B.A.s in 1978-79, but were 12.9 percent of the age 22 population, leading to a ratio of 0.32 in the table.

The very low ratios for blacks, Hispanics, and American Indians are, in fact, the product of two factors: the tendency of these groups to receive higher education degrees at far lower rates than whites, and their tendency, as well, to major in nonquantitative fields. These two factors are displayed in tables 5-3 and 5-4.[31] Blacks, Hispanics, and American Indians are 50 to 62 percent as likely as whites to obtain a baccalaureate, and 30 to 66 percent as likely to receive a Ph.D. Among those who do obtain the two

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[29] Vetter and Babco, op. cit., p. 96. See also *Statistical Abstract of the United States, 1985* (Washington, DC: U.S. Department of Commerce, Bureau of the Census, 1985), pp. 391-392.

[30] Berryman, 1983, op. cit., p. 21.

[31] Ibid., pp. 18 and 20.

Table 5-2.—1978/79 Representation in Quantitatively Based Fields[a] Relative to Representation in Age-Relevant Population by Degree Level and Racial and Ethnic Group

	Degree level			
Racial and ethnic group	B.A.	M.A.	Ph.D.	Professional degrees
Whites	1.13	1.12	1.12	1.12
Blacks	0.32	0.21	0.16	0.35
Hispanics	0.55	0.29	0.21	0.47
American Indians	0.43	0.50	0.33	0.50
Asian-Americans	1.93	2.79	2.71	1.58

[a] Quantitatively based fields for the B.A., M.A., and Ph.D. are defined to include the physical sciences, mathematics, computer sciences, biological sciences, engineering, and economics. For professional degrees the fields are biologically or physically based and defined to include medicine, dentistry, optometry, osteopathy, podiatry, veterinary medicine, and pharmacy.

SOURCE: Sue Berryman, *Who Will Do Science* (New York: The Rockefeller Foundation, 1983), p. 21.

Table 5-3.—1978/79 Representation Relative to Representation in the Age-Relevant Population by Degree Level and Racial and Ethnic Group

Racial and ethnic group	Degree level				
	Associate degree	B.A.	M.A.	Ph.D.	Professional degree
Whites	1.04	1.11	1.10	1.11	1.14
Blacks	0.70	0.51	0.58	0.41	0.35
Hispanics	0.86	0.62	0.36	0.31	0.45
American Indians	0.86	0.57	0.66	0.66	0.50
Asian-Americans	1.27	1.13	1.05	1.33	0.95

SOURCE: Sue Berryman, *Who Will Do Science* (New York: The Rockefeller Foundation, 1983), p. 21.

Table 5-4.—1978/79 Representation in Quantitatively Based Fields[a] Relative to Representation in Total Degrees by Degree Level and Racial and Ethnic Group

Racial and ethnic group	Degree level			
	B.A.	M.A.	Ph.D.	Professional degrees
Whites	1.02	1.02	1.01	0.99
Blacks	0.62	0.36	0.39	0.98
Hispanics	0.88	0.80	0.69	1.04
American Indians	0.75	0.75	0.50	1.00
Asian-Americans	1.71	2.65	2.04	1.67

[a] Quantitatively based fields for the B.A., M.A., and Ph.D. are defined to include the physical sciences, mathematics, computer sciences, biological sciences, engineering, and economics. For professional degrees the fields are biologically or physically based and defined to include medicine, dentistry, optometry, osteopathy, podiatry, veterinary medicine, and pharmacy.

SOURCE: Sue Berryman, *Who Will Do Science* (New York: The Rockefeller Foundation, 1983), p. 21.

degrees, the three minority groups under discussion are 62 to 88 percent as likely as whites to have majored in a quantitative field at the undergraduate level, and 39 to 69 percent as likely to have majored in a quantitative field on the graduate level. The ratios in table 5-2 are the product of the ratios in tables 5-3 and 5-4 for each racial and ethnic group and each degree level.

Asian-Americans are about equal to whites in their likelihood of obtaining higher education degrees. However, they are more than twice as likely to select quantitative majors in college and graduate school. This picture for Asian-Americans may, however, be deceiving. Robert Suzuki claims that 85 to 90 percent of the Asian American scientists and engineers are non-U.S. citizens, or naturalized citizens who immigrated to this country to pursue their college education. This indicates, according to Dr. Suzuki, that:[32]

> American-born Asian/Pacific Americans of second, third and even fourth generation who bear the legacy of 130 years of racial oppression and who gen-

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[32] U.S. Congress, House Committee on Science and Technology, Subcommittee on Science, *Symposium on Minorities and Women in Science and Technology* (Washington, DC: U.S. Government Printing Office, July 1982), p. 12.

> erally trace their ancestry to poor immigrant peasants are probably not over-represented in science and engineering and, indeed they may still be underrepresented, although I know of no definitive studies on this subject.
>
> On the other hand, most of the foreign-born Asian/Pacific Americans in science and engineering come from the more affluent classes in their countries of origin and represent perhaps the top one-hundredth of 1 percent of their country's populations. Consequently, these persons have not suffered the historical discrimination experienced by their American-born counterparts. Moreover, they generally represent an elite class, the cream of the cream, who are likely to do well even as immigrants.

Dr. Suzuki is undoubtedly overstating the case. However, because the high participation rate among Asian-Americans in science and engineering education and employment does not constitute a problem in equality of opportunity, we will use the term "minorities" to refer exclusively to blacks, Hispanics, and Native Americans in this chapter. Asian-Americans will be discussed separately, where appropriate.

Due to limitations of time and space, differences between blacks, Hispanics, and American Indians, between men and women in each minority group and between the different Hispanic subgroups cannot be discussed in this technical memorandum. The omission of a discussion of these differences is not meant to imply that they are insignificant.

The quality of academic preparedness in secondary school is cited by many experts as the greatest factor affecting minorities' academic performance and baccalaureate attainment in college. The greater attrition levels in the sciences of minority groups correlates very highly with measures of academic preparedness, such as high school grades, aptitude test scores, quality of study habits, rigor of the high school curriculum, and perceived need for tutoring. Of those factors, Alexander Astin found that grade average and class rank were more important predictors of undergraduate grades and persistence than were standardized test scores.[33]

Unlike some other disciplines, it is essential to begin the science course sequence at an early stage in the high school curriculum. Fields such as chemistry, physics, and engineering require extensive preparatory coursework. Students in private high schools who have greater access to college preparatory curricula, including advanced mathematics and science courses, than do students in public high schools, tend to choose mathematics and science majors in larger proportions. The poor quality of mathematics and science curricula in many inner-city high schools has been found to be a contributing factor to the low rate of selection of science and mathematics majors among minorities. It has been found that a higher percentage of black students from predominantly white high schools choose mathematics-based majors than blacks from predominantly black high schools.[34] In a study of 474 juniors and seniors at Wayne State University, where one-fifth of the students are black, it was found that:[35]

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[33] Alexander W. Astin, *Minorities in American Higher Education: Recent Trends, Current Prospects & Recommendations* (San Francisco, CA: Jossey-Bass, Inc., 1982), p. 180.

[34] Thomas, op. cit., p. 8.

> Over 70 percent of the white science majors felt their high school training was adequate while less than 50 percent of the black science majors did. Sie and her colleagues found that a number of black students had taken advantage of special opportunities in secondary school: Of the twenty-four black science majors, thirteen went to Cass Technical High School where science is emphasized.

Because of the high-level of preparation required for the sciences many minorities opt for other fields of study. Astin's study revealed that with the possible exception of Puerto Ricans, during their senior year in high school minority students already show a strong preference for an education major and a tendency to avoid majors in the physical sciences and mathematics and in engineering. This was attributed in part to the students relatively poor academic preparation at the secondary school level.[36] Sue Chipman and Veronica Thomas report that "a survey of high school students who were seniors in 1980 indicated that black, Hispanic, and Native American students were only about half as likely to have taken advanced math courses as white students, whereas Asian-American students were about twice as likely to have done so."[37]

The educational level of the minority student's parents plays an important role in determining whether the student will be enrolled in an engineering or science curriculum. Students whose parents have obtained college or graduate degrees are more often enrolled in quantitative majors than are students who have less well-educated parents. Sue Berryman found that "being second generation college not only increases, *but also equalizes,* the choices of quantitative majors across white, black, American Indian, Chicano and Puerto Rican college freshmen."[38] (Asian-American students select quantitative majors at much higher rates than any other group whether their parents have a college education or not.) College-educated parents apparently tend to assume their children will also attend college, and therefore encourage them to enroll in the required preparatory courses. College-educated parents also appear to be better informed about the importance of pre-college training, and expose their children to a greater variety of career options.

The financial resources available to the minority college student play an important role in determining academic success and attrition rates. Minority students typically experience difficulty in financing undergraduate study. They must rely more on scholarship, work-study, and loan programs in contrast to nonminority students, who receive greater family support. In

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[35] Maureen A. Sie, et al., "Minority Groups and Science Careers," *Integrate Education*, vol. 16, May-June 1978, pp. 44-45; quoted in Meyer Weinberg, *The Search for Quality Integrated Education: Policy and Research on Minority Students in School and College* (Westport, CT: Greenwood Press, 1983), p. 288.

[36] Astin, op. cit., pp. 73-74.

[37] Susan F. Chipman and Veronica G. Thomas, "The Participation of Women and Minorities in Mathematical, Scientific, and Technical Fields," commissioned by the Committee on Research in Mathematics, Science, and Technology Education of the National Research Council Commission on Behavioral and Social Sciences and Education, September 1984, p. 49.

[38] Berryman, 1985, op. cit., p. 17.

1975, black and Hispanic college-bound high school seniors estimated that their parents would contribute about $200 a year toward college expenses, while the median figure for whites was over $1,100. That same year minority students comprised one-third of the persons assisted through the major U.S. Office of Education aid programs. Upon graduation from college, immediate employment opportunities may appear more rewarding than advanced study in view of the prospect of further financial difficulties, the academic risk of graduate study (about half of all doctoral candidates fail to complete Ph.D. degrees), and labor market uncertainties.[39] Associated with these financial difficulties are the problems of the working student in general. If a student must hold down a full-time job while in college he or she is less likely to complete his or her baccalaureate.[40]

Factors such as poor academic preparedness and inadequate financial support provide a surface-level explanation of why minorities tend to participate at lower rates in higher education in general, and science and engineering in particular. Underlying these factors are the deeper issues of culture and social class. Sue Berryman describes the importance of these factors as follows:[41]

> Racial and ethnic differences in mathematical achievement that we observe at grade 9 appear at grade 1, [with] blacks, Chicanos, and Puerto Ricans starting school with mean scores on verbal and non-verbal tests of achievement below the national white average.
>
> Two momentous factors contribute to the relationship between ethnicity and mathematical performance at each educational stage: culture and *social class*. Both affect family behavior patterns which in turn powerfully affect children's school performances.
>
> A study of verbal, reasoning, numeric and spatial achievements among Puerto Rican, Jewish, Chinese, and black children at grade 1 shows clear racial and ethnic differences in the *patterns* of these abilities and subsequent studies suggest that ethnic differences in ability patterns at grade 1 persist through elementary and secondary school. More important, although social class has important effects on the *level* of abilities of each group, it does not alter the basic *pattern* of abilities associated with each group.

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[39] National Board on Graduate Education, *Minority Group Participation in Graduate Education* (Washington, DC: National Academy of Sciences, 1976), p. 8.

[40] Astin, op. cit., p. 109.

[41] Berryman, 1985, op. cit., pp. 14-17, the studies cited by Berryman to support her conclusions are the following:

- J. D. Coleman, et al., *Equality of Educational Opportunity* (Washington, DC: U.S. Department of Health, Education, and Welfare, 1966).
- R.H. Dave, "The Identification and Measurement of Environmental Process Variables That Are Related to Educational Achievement," University of Chicago, unpublished doctoral dissertation, 1963.
- R.L. Flaugher, *Project Access Research Report No. 22—Patterns of Test Performance by High School Students of Four Ethnic Identities,* Research Bulletin RB-71-25 (Princeton, NJ: Educational Testing Service, 1971).
- C. Jencks, et al., *Inequality—A Reassessment of the Effect of Family and Schooling in America* (New York: Basic Books, 1972).
- G.S. Lesser, "Cultural Differences in Learning and Thinking Styles," *Individuality in Learning*, S. Messick (ed.) (San Francisco, CA: Jossey-Bass, Inc., 1976).
- G.S. Lesser, et al., *Mental Abilities of Children From Different Social-Class and Cultural Groups,* Monographs of Society for Research in Child Development, Serial No. 102, vol. 30, No. 4, 1965.
- K. Marjoribanks, *Ethnic Families and Children's Achievements* (Sydney: George Allen & Unwin, 1979).
- K. Marjoribanks, *Families and Their Learning Environments* (London: Routledge and Kegan Paul, 1979).

> At the same time, the study shows that middle-class children from the various ethnic groups resemble each other to a greater extent than scores of the lower-class children from the different groups . . . . Social class has a particularly profound effect on the performance of black children, lower class status depressing performance more for these children than for children from the lower classes of other ethnic groups.
>
> Social class seems to be a proxy for *family characteristics* that affect school achievement. For example, an American study showed that characteristics such as the family's press for achievement, language models in the home, academic guidance provided by the home, indoor and outdoor activities of the family, intellectuality in the home—as represented by the nature and quality of toys, games and hobbies available to the child, and work habits in the family together correlated at 0.80 with children's achievement scores.
>
> An analysis of 1972 data on blacks' choice of and persistence in a science major found that family socioeconomic status affects blacks' choice of a science major. Higher family socioeconomic status increased the rate of choosing science majors, the effect operating by increasing the mother's educational aspirations for the student and the student's high school mathematical achievement. **When white and black students were equated on the intervening variables, blacks had a higher probability of choosing a science major than whites** [emphasis in the original].

Sue Chipman and Veronica Thomas find that "lower educational and career aspirations associated with lower socio-economic status may undermine minority students perception of the utility of mathematics . . . ." She adds that it is "quite possible that minority students, again because of their socio-economic status, have still less knowledge of the relationship between mathematics and particular occupational goals than do students in general."[42]

Betty Vetter reports on a study carried out by the National Opinion Research Center in 1980 for the Departments of Defense and Labor.[43] It identified a nationally representative sample of nearly 12,000 16- to 23-year old men and women, and administered to this group the Armed Forces Qualification Test (AFQT), a general measure of trainability and enlistment eligibility for the armed forces. The test showed that youths from higher socioeconomic groups scored higher than those from lower socioeconomic groups; that white youths generally did better than black or Hispanic youths; **but the strongest single predictor of both the AFQT score and reading ability was the mother's educational level.** Later analyses suggested that the measured correlation of mother's education with test performance approximated the combined measured correlation of the four variables usually used to determine socioeconomic status: mother's education, father's education, average family income, and father's occupational status.

The differences were substantial. Youth whose mothers had completed eighth grade or less scored in the 29th percentile on the tests. Those whose mothers had completed high school had an average percentile score of 54. Those whose mothers were college graduates or more averaged 71.

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[42] Chipman and Thomas, op. cit., p. 50.

[43] Betty M. Vetter, "The Emerging Demographics—Effect on National Policy in Education and on a Changing Workforce," contractor report prepared for the U.S. Congress, Office of Technology Assessment, May-June 1985, p. 50.

The effect of socioeconomic status or class on minorities' persistence in the science and engineering educational pipeline is a cause for optimism among some, pessimism among others. Sue Berryman paints the optimistic picture:[44]

> In the short run, specially designed interventions can increase minority shares of quantitative degrees by targeting those who have the capacities to respond to these interventions, but who, in their absence, would probably not pursue a quantitative training program and career. In the long run, the trends favor increased minority representation in the quantitative fields. The growing number of second generation black and Hispanic college students will be an important factor in increasing the representation of these groups in the nation's scientific and engineering labor force.

Betty Vetter makes the more pessimistic case. She points out that 44 percent of all black households and 23 percent of Hispanic households are headed by single women. Nearly 72 percent of all black families and 46 percent of Hispanic families with incomes below the poverty level were maintained by single women. Seventy percent of all black children are being brought up in poverty. She concludes that:[45]

> We can anticipate an increasing school drop-out rate among Hispanic and black children, growing up with young, single mothers who, because they have too little education themselves, are unlikely to be able to provide the incentives that may be required to keep their children in school and learning . . . . If present trends continue, we can anticipate that more of [the baby boom echo group] will drop out of school or out of math and science classes at earlier stages, and far fewer of them will obtain the educational preparation required for professional participation in quantitative fields.

In reality, both pictures may be true. An increasing number of minority students with middle class, college-educated parents, will undoubtedly enroll in higher education and major in science and engineering. However, an even larger number of black and Hispanic students from poor, single-parent households will find a college education and a science or engineering career difficult to achieve due to poor academic preparedness.

Differential Treatment in the Work Force

As was the case for women, minorities have a somewhat different experience from that of whites in the science and engineering work force. Recent NSF data[46] indicate that unemployment rates among black and Asian-American scientists and engineers were significantly higher than those of whites: 4.6 and 3.3 percent, respectively, versus 2.1 percent for whites. The unemployment rate for Hispanic scientists and engineers, by contrast, was about the same as that of whites, while Native American scientists and engineers had substantially *lower* unemployment rates. Black, Hispanic, and Native American scientists and engineers were somewhat less likely than whites to be employed in science and engineering (81 to 83 percent versus 87 percent). Asian-American scientists and engineers were somewhat more likely (90 percent) to be so employed.

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[44] Berryman, 1985, op. cit., p. 4.

[45] Vetter, 1985, op. cit., p. 7.

[46] *Women and Minorities in Science and Engineering*, op. cit., pp. viii, ix, 20-24.

Blacks and Hispanics reported significantly lower salaries than whites in science and engineering. The average salary for whites in all science and engineering fields was $34,200; that for blacks $30,100; and that for Hispanics $31,500. The salary differentials varied from lows of $500 between white and Hispanic environmental scientists and $900 between white and black computer specialists, to highs of $9,800 between white and Hispanic mathematical scientists, and $7,000 between white and black environmental scientists. Asian and Native American scientists and engineers reported salaries almost identical to those of their white counterparts.

Despite these differences in salaries and unemployment rates, analysts consulted by OTA did not report strong evidence for discrimination in the work force against minority scientists and engineers.

EFFECTIVENESS OF PROGRAMS TO PROMOTE PARTICIPATION

As shown in the preceding sections, many of the factors that inhibit participation in science and engineering by women and minorities are related to pre-college experience, both academic and nonacademic. These factors include overall poor academic preparedness (for blacks and other minorities); lack of exposure to the needed science and mathematics sequence (for minorities and women); socialization factors that underemphasize the desirability or appropriateness of a scientific or engineering career (especially for women); poverty and inadequate financial resources (especially for minorities); and family characteristics that affect school achievement. To some degree, it appears that these early factors can be overcome, or at least compensated for, by special programs designed to facilitate access to science and engineering education for disadvantaged cultural groups.

In 1983 the Office of Opportunities in Science of the American Association for the Advancement of Science (AAAS) conducted an "assessment of programs that facilitate increased access and achievement of females and minorities in K-12 mathematics and science education" for NSF.[47] The assessment was based on a survey questionnaire to the directors of more than 400 pre-college intervention programs for women and minorities, and site visits to more than 50 exemplary projects in different regions of the United States. Time and budget limitations precluded AAAS from carrying out formal evaluations of the programs it surveyed, but the results of such evaluations, where they had been performed independently, were requested from program directors in the survey.

AAAS found that "the primary feature of successful programs for minorities and females seems to be that they involve the students in the 'doing' of science and mathematics and convey a sense of their utility." Such "exemplary programs" are "sensitive to the group or groups they are intended to serve and address these audiences' fundamental needs for academic enrichment and career information:[48]

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[47] Shirley M. Malcom, et al., *Equity and Excellence: Compatible Goals* (Washington, DC: American Association for the Advancement of Science, December 1984).

[48] Ibid., pp. vii-viii.

> Exemplary programs for minorities recognize the deficiencies in performance many students are likely to have and stress rigorous academic preparation in mathematics, science and communications . . . . Projects for females focus heavily on career awareness—on the utility of mathematics and science to whatever they might want to do. Young women are encouraged to take all the courses available to them in high school. They are shown models of science and engineering professionals and students who "are making it" in these fields.

In general, AAAS found that these programs "have demonstrated that there are no inherent barriers to the successful participation of women and minorities in science or mathematics," if these groups are provided with "early, excellent, and sustained instruction in these academic areas." AAAS also found that:[49]

> Successful intervention programs are those that have strong leadership, highly trained and highly committed teachers, parent support and involvement, clearly defined goals, adequate resources, follow-up and evaluation. For the positive effects to be sustained, these programs must eventually be institutionalized, that is, made part of the educational system . . . .
>
> Scientists and engineers from the affected groups must be involved in the planning as well as in the implementation of projects . . . .
>
> Intervention programs must begin early and must be long-term in nature; "one-time" or short-term efforts do have a place for motivational, informational, supplemental or transitional purposes.

AAAS reported on a number of specific intervention programs that could document their success. An evaluation of the Mathematics, Engineering, Science Achievement (MESA) Program of the Lawrence Hall of Science in Berkeley, CA, which includes 16 centers, 131 high schools and about 3,400 students, found that:[50]

> Of recent MESA graduates, 90 percent have attended a college or university and approximately 66 percent have pursued a math-based field of study. MESA seniors performed significantly higher than college-bound seniors of similar racial/ethnic backgrounds across the nation. MESA seniors at sampled schools did not differ significantly on SAT performance from the total population of college-bound seniors . . . . despite the fact that the sampled schools were among the lowest-achieving schools in the state.

The Summer Science Enrichment Program at Atlanta University provides summer instruction in mathematics, science, and communication to high school juniors, most of whom are black. All 338 of the students who have participated in this program since its inception in 1979 have gone on to college, and 95 percent of them have majored in a quantitative field. It should be noted that this program selects students with demonstrated interest and performance in science and mathematics.

The Philadelphia Regional Introduction for Minorities to Engineering (PRIME) is a consortium of more than 34 businesses, 14 government and civic organizations, and 7 universities and public schools which has operated in the Philadelphia area for more than 9 years. It is a supplementary program in science and mathematics which begins in seventh grade and takes students through high school. Of the more than 820 high school seniors who have graduated from this program since 1977, more than 60 percent have chosen careers in engineering and/or technology. In addition, the number of minority students in the Philadelphia area enrolled in academic-track high school programs has tripled during the years of operation of the PRIME project, with one-third of those students in the PRIME project.

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[49] Ibid., p. viii.

[50] Ibid., p. 56.

The Professional Development Program (PDP) of the University of California, Berkeley, is a faculty-sponsored program which recruits sophomores from 45 public and private high schools in eight districts to participate in special summer academic programs and Saturday classes during the school year. Over 60 percent of the students are women, and 75 percent are black or Hispanic. Of the 421 students from 60 local schools that have completed the program, "90 percent have gone on to college and a substantial number are in quantitative fields."[51] The average SAT mathematics scores of the 1981-82 PDP senior class was 598.

These projects illustrate the general point made by AAAS that intervention programs at the pre-college level can be effective in increasing the participation of women and minorities in science and engineering education. A far more systematic and thorough evaluation would be required to document the extent to which changes observed can be reliably attributed to the effects of the programs themselves. It should be noted that participation in these programs is voluntary, so those affected by the programs tend to be students who are already somewhat motivated toward science and engineering.

POLICY IMPLICATIONS

The AAAS report on *Equity and Excellence: Compatible Goals,* cited above, states that "the magnitude and complexity of the problem" of equality of access to scientific and engineering careers requires "a large and continuing effort that specifically targets large sectors of our society . . . ." The NSF Authorization Act of 1981, Section 35(a), required the President to submit to Congress, by January 29, 1982, a report "proposing a comprehensive national policy and program, including budgetary and legislative recommendations, for the promotion of equal opportunity for women and minorities in science and technology." That report has neither been prepared nor transmitted to Congress. Therefore, there is, at this writing, no national policy or program to promote equal opportunity in science and engineering for women and minorities.

The Director of NSF did submit a report to Congress on December 15, 1981, in conformity with Section 34(b) of the 1981 NSF Authorization Act which required "a report proposing a comprehensive and continuing program at the Foundation to promote the full participation of minorities in science and technology." However the report contained neither budgetary nor legislative recommendations as required by the Act, and contained little more than restatement of existing policies and programs.[52] In fact the report attempted to rationalize budget *cuts* in a number of programs that were created in the 1970s, including the Minority Institutions Science Improvement Program (MISIP), the Resource Centers for Science and Engineering Program (RCSE), the Student Science Training (SST) Program, the Opportunities for Women in Science Program (OWS), and the Visiting Professorships for Women Program (VPW).

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[51] Ibid., p. 56.

In the absence of executive branch leadership in this area, the AAAS study recommended that the following steps be taken by the Federal Government:[53]

> Federal support for programs to improve the quality of pre-college education in science, mathematics, and technology should require that proposals specifically address themselves to plans for serving women, minority, and disabled student populations.
>
> Federally supported programs for teacher training and retraining should require that teaching methods and career and equity aspects be included, along with a rigorous focus on improving competence in subject content.
>
> The Federal Government should support dissemination of models previously shown to be effective in improving science and mathematics education for women and minorities, including technical assistance on management and evaluation systems . . . .
>
> . . . . previously supported programs that had a strong positive educational impact on women and minorities should be reexamined for possible reinstitution. Of particular interest in this regard are the RCSE and SST programs.

In order to better understand the policy implications of the problems experienced by women and minorities related to participation in science and engineering education, OTA sponsored a panel discussion among experts[54] in this area on July 2, 1985. The findings of the panel are presented below:

Issue 1--Keeping Options Open

1. The self-perception of women and minorities of their inability to succeed in science and mathematics courses is frequently reinforced by the system's perception of their inability to do science and engineering.
2. Opportunities should be provided for this population to experience success in science and mathematics courses prior to grade 9 as well as opportunities for them to perceive the variety of career options and lifestyles that are based on these disciplines.
3. The Federal Government should support improvements in the training of junior high school science and mathematics teachers, the development of counseling programs involving teachers and parents and the identification and funding of model programs which enhance the self-perception of students.
4. Tests should be developed that are better indicators of the potential of women and minorities to succeed in science and mathematics careers.

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[52] National Science Foundation, "Proposals of the National Science Foundation to Promote the Full Participation of Minorities and Women in Science and Engineering," typescript, December 1981.

[53] Malcom, op. cit., p. 30.

[54] The panel consisted of Lloyd Cooke, Michael Crowley, Maria Hardy, Shirley Malcom, Shirley McBay, Denis Paul, Willie Pearson, Luther Williams, Allan Hoffman, and Jerrier Haddad.

Issue 2—Reducing Attrition

1. The graduate student pipeline should be enlarged by providing long-term support for promising minority and women students who are satisfactorily progressing toward the Ph.D. degree in science and engineering with identification and support beginning at the junior year in college.
2. The circumstances which lead to the success of women and minority students in science and engineering should be studied, and the knowledge obtained applied to improving the retention of less successful students.
3. Opportunities for early experience in research should be provided for minority and women students beginning at the undergraduate level. Existing efforts at the graduate level should be strengthened.
4. The Federal Government should disseminate and encourage programs and operating conditions which demonstrably facilitate the retention of women and minorities in science and engineering.
5. Federal Government affirmative action guidelines for recipients of Federal funds should be extended to protect against the following:
   - sexual harassment of women students, and
   - bias of some foreign professors whose cultures hold women in low status.

In addition to the above options for increasing the pool size and reducing attrition, it is probable that further gains might be realized if more were known about how different minority subgroups respond to different options. For example, differences may exist:

- for blacks, American Indians, and Hispanics;
- within the various Hispanic subgroups (e.g., Chicanos, Puerto Ricans, and Cubans); and
- for minority and nonminority women.

This suggests the need for support of studies on this issue. Further suggestions are provided in appendix B.

Appendix A: The Education and Utilization of Biomedical Research Personnel

Introduction

As a nation, we spend $300 billion per year on health care, or 10 percent of the gross national product (GNP). National attention to biomedical research and its potential for health benefit has been consistently strong since World War II, driven by the hope that science will provide us with longer and healthier lives.

These early beginnings lead to a relatively high level of Federal support for both research and training in the biomedical sciences in comparison to other disciplines. The Government, through the National Institutes of Health (NIH), made an early commitment to the training of biomedical research personnel through the establishment of the NIH training and fellowship programs. In addition, Congress has ensured a substantial and consistent level of support for biomedical research through favorable appropriations to NIH, the parent agency for federally funded biomedical research programs. As a result of this two-pronged Federal approach to the biomedical sciences through support of both research and training programs, the biomedical research field has suffered few of the critical personnel shortages and/or surpluses found in other scientific disciplines. It is, therefore, worth examining the Federal program for training and supporting biomedical research personnel in some depth. It is an example of a continuous and mostly successful Federal personnel policy in an important scientific field.

Basic Biomedical Research Personnel [Ph.D.s]

Training

The higher education training system in basic biomedical research consists of at least two, and often three, stages. Virtually all biomedical scientists obtain a doctorate, although exceptions do exist. In addition, the Institute of Medicine (IOM) estimates that 60 percent of Ph.D. recipients in the basic biomedical sciences go on to postdoctoral appointments. Postdoctoral appointments are considered by some to be a holding pool for the Ph.D. population in search of employment. Recently, it has been suggested that postdoctoral training is also an essential educational experience for the biomedical scientist, and essential to success as an independent investigator.[1] Rapidly developing areas of research, it is argued, require more intensive and extensive training.

IOM estimates that of the postdoctoral population with doctorates from U.S. universities 30 percent are women and 10 percent hold foreign citizenship.[2] Foreign scientists have comprised approximately one-third of the total population of biomedical postdoctoral appointees since 1975.

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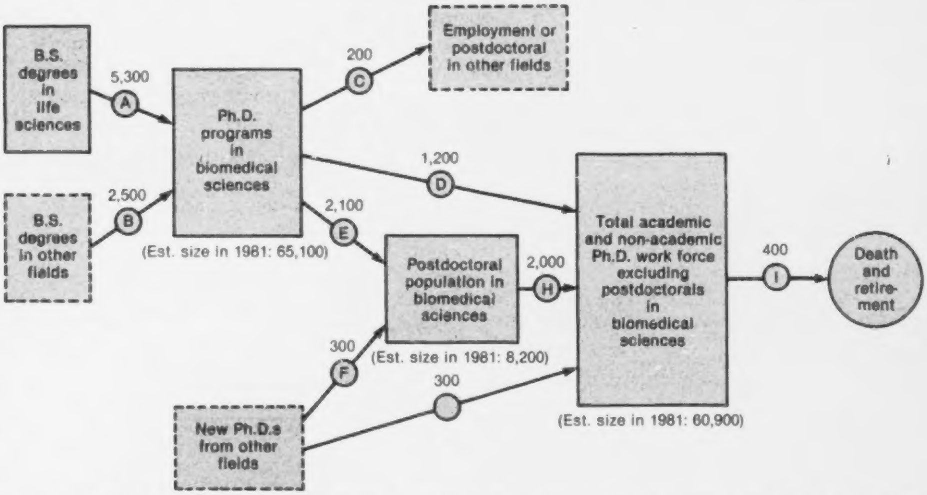
[1] Institute of Medicine, *Personnel Needs and Training for Biomedical and Behavioral Research: 1983 Report* (Washington, DC: National Academy Press, 1983).

[2] Ibid., p. 61.

Figure A-1.—Doctoral Training System in the Biomedical Sciences


B.S. degrees in life sciences
5,300
A
B.S. degrees in other fields
2,500
B
Ph.D. programs in biomedical sciences
(Est. size in 1981: 65,100)
200
C
Employment or postdoctoral in other fields
1,200
D
2,100
E
Postdoctoral population in biomedical sciences
(Est. size in 1981: 8,200)
2,000
H
300
F
New Ph.D.s from other fields
300
Total academic and non-academic Ph.D. work force excluding postdoctorals in biomedical sciences
(Est. size in 1981: 60,900)
400
I
Death and retirement

NOTE: Estimates represent the average annual number of individuals following particular pathways during the 1973-81 period. No estimates have been made for immigration, emigration, or reentry into the labor force.

SOURCE: IOM Report on *Personnel Needs*, 1983.

The typical biomedical researcher spends 4 years in undergraduate work, 5 to 7 years in graduate school to receive the Ph.D., and 2 to 4 years in a postdoctoral appointment. Figure A-1 illustrates the doctoral training system in the biomedical sciences.

Figure A-2 shows the distribution of primary sources of support for graduate students enrolled in Ph.D.-granting biomedical science departments, in 1975 and 1981. In addition to Federal sources of support, biomedical science students rely on teaching assistantships and self-support. NIH is the major source of support for postdoctoral training in clinical research, supplying nearly 90 percent of all training funds.[3] The National Science Foundation (NSF) provides for approximately 45 predoctoral fellowships per year in the biomedical sciences.[4]

It is only in the past 12 years that Federal programs for biomedical research training have been centralized. In 1973, the Nixon Administration proposed phasing out all training grant and fellowship programs of NIH; the Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA); and the Health Resources Administration (HRA). Congress responded, in 1974, by passing the National Research Service Award (NRSA) Act (Title I, Public Law 93-348) that consolidated previous research training authorities under the Public Health Service Act. The NRSA Act is the only existing authority under which NIH supports training for biomedical and behavioral research careers. Threats to the NRSA program have appeared in every administration budget between 1978 and 1985 only to be relieved by Congress.

NIH devotes 10 percent of NRSA appropriations to special programs in minority access, the Medical Scientists program leading to a combination M.D./Ph.D. degree, and short-term training programs in medical schools. Predoctoral training accounts for 35 percent of the NIH NRSA program. The program's major emphasis, however, is on postdoctoral training, which receives 55 percent of NRSA funds in

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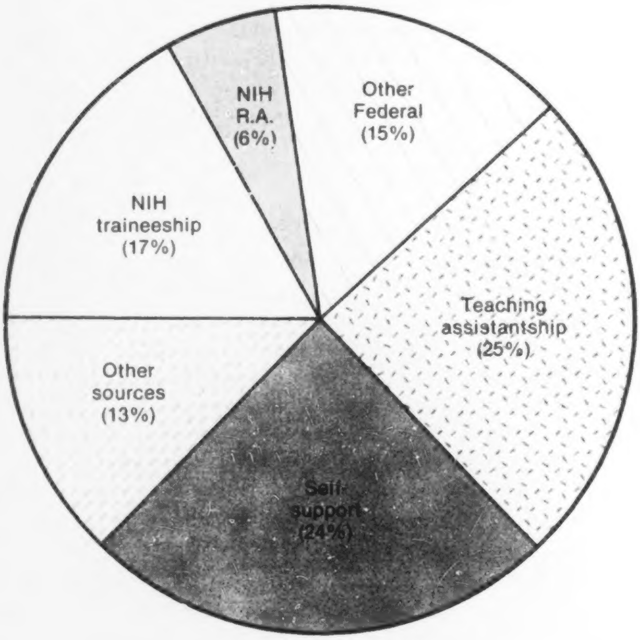
[3] Thomas E. Malone, "Assuring the Supply of Clinical Investigators" (typescript), National Institutes of Health, 1981.

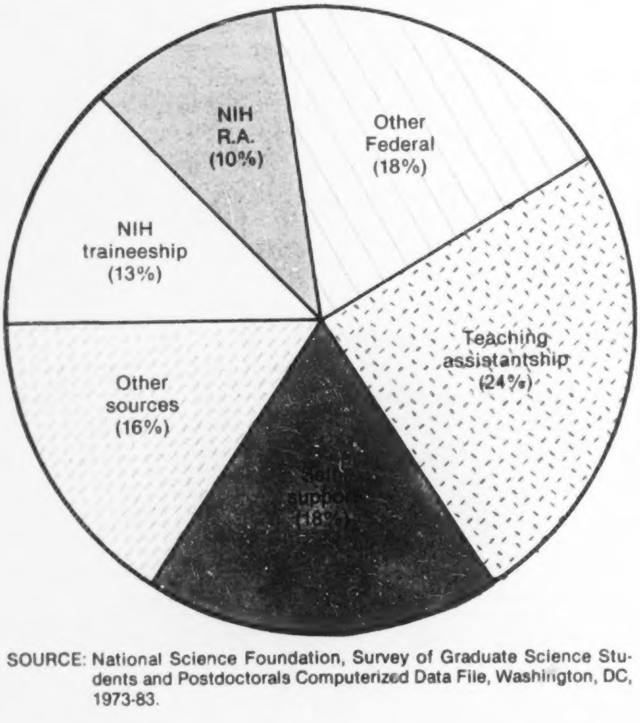
[4] Personal communication with Terence Porter, Science and Engineering Education, National Science Foundation, March 1985.

Figure A-2.—Distribution of Primary Sources of Support for Graduate Students Enrolled in Ph.D.-Granting Biomedical Science Departments, 1975 and 1981

1975



1981



SOURCE: National Science Foundation, Survey of Graduate Science Students and Postdoctorals Computerized Data File, Washington, DC, 1973-83.

the belief that changing national needs can be most quickly met by a large and well-trained postdoctoral pool.

Funds are awarded for predoctoral and postdoctoral stipends through a system of individual fellowships and institutional training grants. Institutional training grants must survive peer review in national competition, and require a substantial commitment on the part of the institution to share in the maintenance of a training environment. They are limited to those institutions with the tradition and history of producing high-quality investigators and the financial resources to accept the necessary cost-sharing burden. Institutional training grants provide the program director with a number of full-time training positions. Individual fellowship awards, on the other hand, allow the applicants to develop a research training project under the supervision of a sponsor. The individual fellow tends to be further along in the training process than the institutional fellow (i.e., at the postdoctoral level). In 1985, the average annual stipend for the predoctoral fellowship is $6,552; the range for postdoctoral awards is $16,000 to 30,000 per year.

By 1971, NIH training grants and fellowships supported or assisted 37.3 percent of the Nation's full-time graduate students in the medical sciences and 1 percent in the life sciences.[5] Between 1961 and 1972, NIH programs furnished financial assistance through fellowships and institutional training grants to more than 30,000 graduate (predoctoral) students in the health-related disciplines. In addition, more than 27,000 biomedical scientists received postdoctoral support through NIH programs.[6] Since 1972, individual awards for predoctoral students have been eliminated and the numbers of predoctorals on training grants have been reduced. Between fiscal years 1969 and 1980, the number of predoctoral students receiving NIH support dropped by about 50 percent (see figure A-3). Nevertheless, between 1973 and 1983, more than one out of every three Ph.D. recipients in health-related fields had received some NIH training support while in graduate school.[7]

Allocation of Resources Between Predoctoral and Postdoctoral Training

The tradition of postdoctoral training in the biomedical sciences is a long one, possibly because NIH training programs are the oldest of their kind. The biomedical research system shows great sensitivity to the supply and demand for individuals in both groups. The amount of support available for postdoctoral v. predoctoral training has a definite effect on the supply of manpower in the biomedical sciences. Starting in the early 1970s through 1981, the number of postdoctoral appointments increased 9 percent per year.[8] (See figure A-4.) During this same period, Ph.D. production was fairly constant. Most of the postdoctoral expansion has occurred in medical schools, which employ 65 percent of the postdoctoral scientists in biomedical sciences. In fact, most of the growth has been in the 20 largest universities.[9]

Steady growth in the postdoctoral population may be a combined result of an increase in the numbers of new Ph.D. recipients and an increase in the length of time spent in postdoctoral appointments. IOM believes that the prolongation of apprenticeship has been a major factor in the expansion of the postdoctoral pool in the biomedical sciences.[10] The reason for the extension of postdoctoral training

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[5] Malone, op. cit.

[6] National Research Council, Office of Scientific and Engineering Personnel, *Survey of Earned Doctorates, 1920-81*.

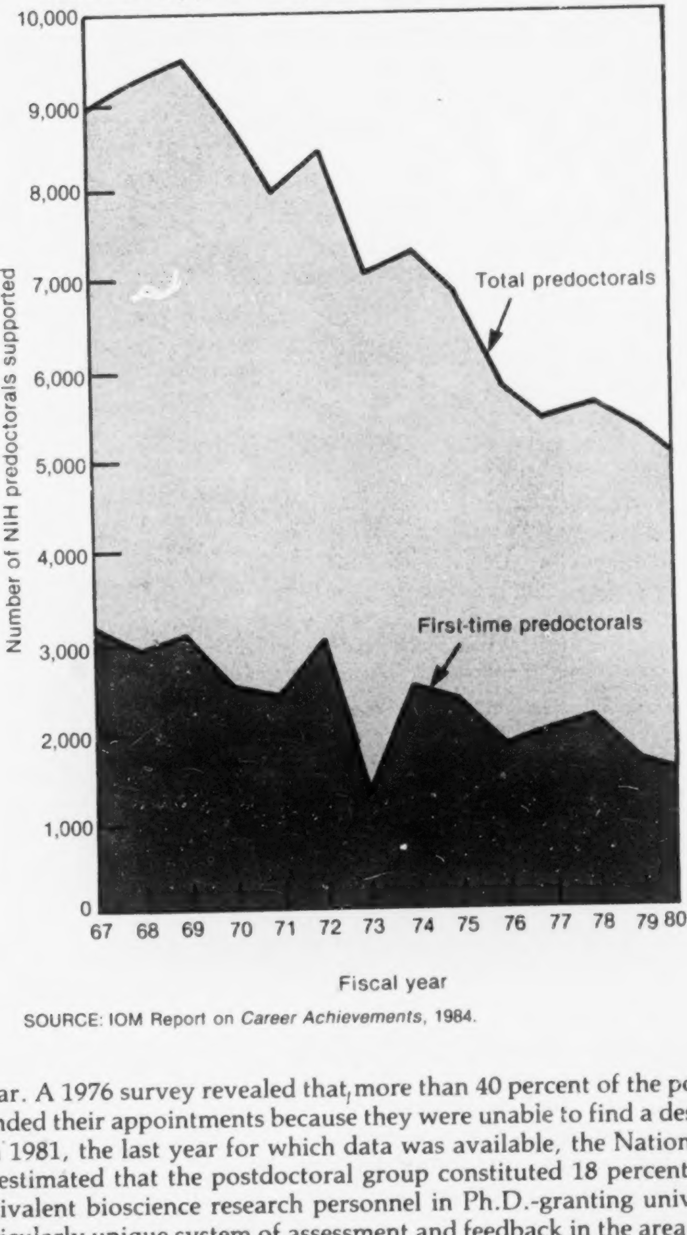
[7] Institute of Medicine, *Report of a Study: The Career Achievements of NIH Predoctoral Trainees and Fellows* (Washington, DC: National Academy Press, 1984).

[8] Institute of Medicine, *Personnel Needs* (Washington, DC: National Academy Press, 1983).

[9] National Science Foundation, *Academic Science: R&D Funds 1975-1983*, Surveys of Science Resource Series (Washington, DC: U.S. Government Printing Office (annual)).

[10] Institute of Medicine, *Personnel Needs*, op. cit., p. 60.

Figure A-3.—Number of Predoctoral Trainees and Fellows Supported by NIH, Fiscal Years 1967-80



SOURCE: IOM Report on *Career Achievements*, 1984.

is not clear. A 1976 survey revealed that more than 40 percent of the postdoctorals had extended their appointments because they were unable to find a desirable position.[11] In 1981, the last year for which data was available, the National Research Council estimated that the postdoctoral group constituted 18 percent of the full-time equivalent bioscience research personnel in Ph.D.-granting universities.[12]

A particularly unique system of assessment and feedback in the area of biomedical and behavioral research personnel needs was established through law in 1974 when Congress passed the NRSA Act. This Act mandated that the National Academy of Sciences:

> . . . establish (A) the Nation's overall need for biomedical and behavioral research personnel (B) the subject areas in which such personnel are needed and

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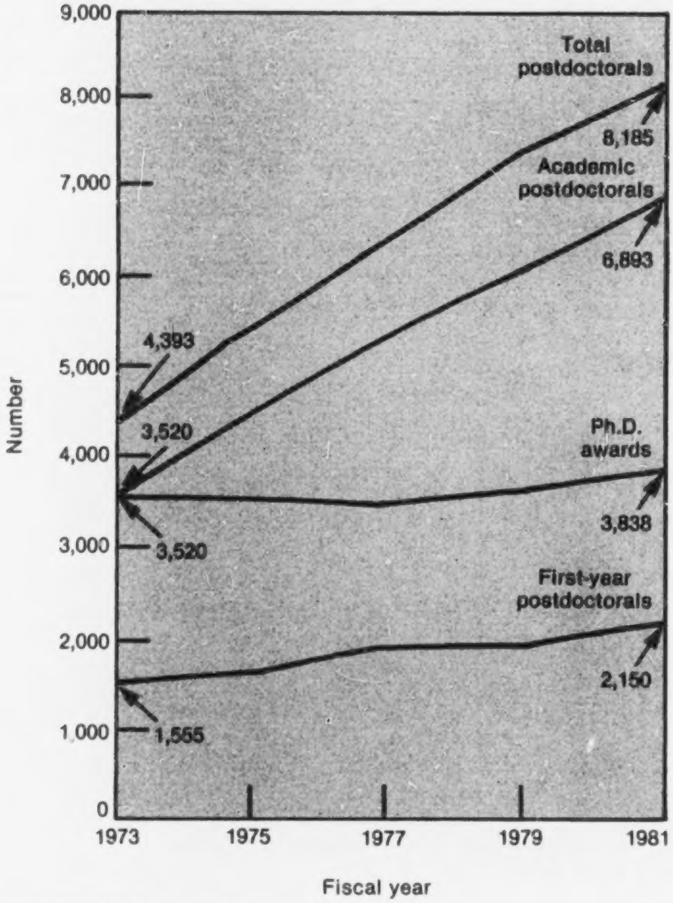
[11] P.E. Coggeshall, et al., "Changing Postdoctoral Career Patterns for Biomedical Scientists," *Science*, vol. 202, Nov. 3, 1978, pp. 487-493.

[12] National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy Press, 1981).

Figure A-4.—Estimated Growth in the Numbers of Ph.D. Awards, Academic Postdoctoral Appointments, and First-Year Postdoctoral Appointments in the Biomedical Sciences, 1973-81



SOURCE: IOM Report on *Personnel Needs*, 1983.

> the number of such personnel in each such area, and (C) the kinds and extent of training which should be provided such personnel.[13]

In 1975, the committee on a study of National Needs for Biomedical and Behavioral Research Personnel was formed under the aegis of the Commission on Human Resources, and later transferred to IOM. During its first 9 years, the committee published seven reports projecting the near-term demand for research personnel in biomedical and behavioral research.

The potential influence of this committee is impressive, as it is mandated to make recommendations to the Federal Government on the size of federally sponsored training programs for biomedical and behavioral scientists. It also makes recommendations for allocation of traineeships between predoctoral and postdoctoral students. To a large degree, the agencies have been responsive to these recommendations. The discrepancy between the level of support recommended by IOM and the actual funding level set by NIH has been small in recent years. Decisions regarding distribution of traineeships and fellowships, however, are left to the agency.

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[13] U.S. Congress, Title I of the National Research Act of 1974 (Public Law 93-348), Section 473.

In recent reports (1981 and 1983), the committee has recommended that the agencies change the allocation of training grants from predominantly predoctoral training to predominantly postdoctoral. This recommendation was made in response to the growth of the predoctoral population that occurred in the 1970s. The higher levels of Federal support for predoctoral training relative to levels of support for postdoctoral training which occurred in the 1970s contributed, in part, to the current slight surplus of biomedical Ph.D.s.

Harrison Shull, former Chairman of the Commission on Human Resources of the National Academy of Sciences, believes that the agencies should use their ability to shift funds quickly between predoctoral and postdoctoral support as a means of responding to a fluctuating job market. Postdoctoral funds can be increased when the supply of new Ph.D.s is high and demand is low; when supply is insufficient to meet demand, funds can be shifted the other way, towards more predoctoral support. This "fine-tuning" mechanism can work only if the supply of traineeships is controlled and steady.[14]

Demographics and Employment Outlooks for the Biomedical Ph.D.

The number of doctorate degrees awarded annually to bioscientists has been relatively constant since 1972. Bioscience baccalaureate degrees have been declining since 1976, and bioscience graduate enrollments peaked in 1978. In the long term, the attrition rate from the active pool of researchers will increase in the 1990s as the population ages, creating more academic positions. If graduate school enrollments continue to decline as the size of the college-age population declines, there could be a small decline of Ph.D. output in the late 1980s and 1990s. If this decline does, in fact, occur, there could be a temporary shortage of biomedical research personnel in the next decade.

The key factors influencing potential shortages or surpluses in this market are Federal funding for biomedical research, and graduate and medical school enrollments. If Congress continues to appropriate a steady level of funding to NIH, then, in a sense, the demand is set. Should the Federal Government suddenly increase or decrease its level of research support in the biomedical sciences, shortages or surpluses could occur.

The total biomedical Ph.D. labor force approached 70,000 in 1981. Half of these individuals were employed in academic institutions whose population has been growing at a rate of 4 percent per year. Employment in the industrial sector has been growing at a rate of 8.5 percent and self-employment at a rate of 24.7 percent (see table A-1).

Next to academia, the industrial sector is the second largest employer of biomedical scientists. Most biomedical Ph.D.s in industry are employed by chemical and pharmaceutical manufacturers. Recently, the biotechnology industry has shown rapid growth, and it is possible that some areas of commercial biotechnology may experience temporary shortages, as investigators attempt to catch up with the latest developments in a new field. A collaborative survey of biotechnology firms conducted by IOM and the Office of Technology Assessment in 1983 revealed that one-third of the respondents had experienced shortages in one or more specialties. The three specialties most often cited were bioprocess engineering, recombinant DNA molecular genetics, and gene synthesis.[15]

Emerging fields will experience temporary shortages of trained personnel as new research opportunities become available. It is the view of some that the postdoc-

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[14] Harrison Shull, "The Ph.D. Employment Cycle—Damping the Swings," *The National Research Council in 1978: Current Issues and Studies* (Washington, DC: National Academy of Sciences, 1978), pp. 149-163.

[15] U.S. Congress, Office of Technology Assessment, *Commercial Biotechnology: An International Analysis* (Washington, DC: U.S. Government Printing Office, January 1984).

Table A-1.—Current Trends in Supply/Demand Indicators for Biomedical Science Ph.D.s

	Fiscal year							Growth rate from 1975 to latest year	Latest annual change	Average annual change from 1975 to latest year
	1975	1976	1977	1978	1979	1980	1981			
1. Supply indicators (new entrants):										
a. PH.D. production	3,515	3,578	3,465	3,516	3,644	3,823	3,838	1.5%	0.4%	54
b. Percent of Ph.D.s without specific employment prospects at time of graduation	6.4%	6.3%	7.2%	6.0%	5.2%	4.8%	5.5%	−2.4%	14.6%	−0.2%
c. Postdoctoral appointments	5,484	n/a	6,403	n/a	7,419	n/a	8,185	6.9%	5.0%[a]	450
d. B.A. degrees awarded	50,493	52,642	51,783	49,701	47,717	45,106	41,476	−3.2%	−8.0%	−1,503
2. Demand indicators (R&D funding):										
a. National expenditures for health-related R&D (1972$, bill.)	$3.70	$3.81	$3.97	$4.13	$4.31	$4.48	$4.44	3.1%	−0.9%	$0.123
b. Biomedical science R&D expenditures in colleges and universities (1972 $, bill.)	$1.19	$1.26	$1.27	$1.34	$1.35	$1.43	$1.49	3.8%	4.2%	$0.05
c. NIH research grant expenditures (1972 $, bill.)	$0.897	$0.944	$1.00	$1.06	$1.17	$1.20	$1.19	4.8%	−0.8%	$0.05
d. Ph.D. faculty/student ratio[b]	0.058	n/a	0.056	n/a	0.063	0.067 (est.)	n/a	2.2%	6.3%	0.002
3. Labor force:[a]										
a. Total	40,698	n/a	55,167	n/a	62,590	n/a	69,076	5.3%	5.1%	5,063
b. Academic (excluding postdoctorates)	28,339	n/a	30,390	n/a	33,687	n/a	36,497	4.3%	4.1%	1,360
c. Business	6,645	n/a	6,918	n/a	8,461	n/a	9,957	7.0%	8.5%	552
d. Government	4,522	n/a	4,567	n/a	5,075	n/a	5,406	3.0%	3.2%	147
e. Hospitals/clinics	1,950	n/a	2,296	n/a	2,272	n/a	2,798	6.2%	1.3%	141
f. Nonprofit	1,221	n/a	1,544	n/a	1,854	n/a	2,083	9.3%	6.0%	144
g. Self-employed	836	n/a	864	n/a	1,197	n/a	1,860	14.3%	24.7%	171
h. Other (including postdoctorates)[c]	6,667	n/a	8,642	n/a	8,899	n/a	9,644	6.3%	4.1%	496
i. Unemployed and seeking	518	n/a	810	n/a	690	n/a	831	n/a	9.7%	52
4. Biomedical enrollments:										
a. Graduate	38,314	39,322	39,260	43,787	43,378	42,969	42,117	1.6%	−2.0%	634
b. Medical and dental schools	74,222	77,011	79,279	81,934	84,761	86,502	88,254	2.9%	2.0%	2,339
c. Estimated undergraduate[d]	424,539	439,946	425,863	406,373	374,869	386,236	n/a	−1.9%	3.0%	−7,661
d. Total biomedical graduate and undergraduate enrollment	537,075	556,279	544,402	532,094	503,008	515,707	n/a	−0.8%	2.5%	−4,274

[a] Since labor force data are not available for 1980, latest annual change represents average growth rate from 1979-81.

[b] Ratio of academically employed Ph.D.s to a 4-year weighted average of total graduate and undergraduate enrollments (WS), where $(WS)_t = 1/6(S_t + 2S_{t-1} + 2S_{t-2} + S_{t-3})$.

[c] Also includes FFRDC laboratories.

[d] Estimated by the formula $U_i = (A_{i+2}/B_{i+2})C_i$, where U_i = biomedical science undergraduate enrollment in year i; A_{i+2} = biomedical science baccalaurate degrees awarded in year i + 2 (excluding health professions); B_{i-2} = total baccalaureate degrees awarded in year i + 2; C_i = total undergraduate degree-credit enrollment in year i (excluding first professional).

SOURCE: Institute of Medicine, *Personnel Needs and Training for Biomedical and Behavioral Research, 1983*, p. 52.

toral pool will be the critical element in ensuring an efficient and timely transition to steady-state supply, for postdoctorals are the most skilled in research methods and problem-solving and can most easily adapt to new concepts and new tools.

Clinical Biomedical Research Personnel [M.D.s]

The application of scientific advances to maintain good health and prevent and treat disease is the goal of *clinical*, as opposed to *basic* biomedical research. For the purposes of this report, clinical investigation includes research on: 1) patients or samples derived from patients as part of a study of the causes, mechanisms, diagnosis, treatment, prevention, and control of disease; or 2) research on animals by scientists identifiable as clinical investigators on the basis of other work.[16]

In general, clinical investigation requires the participation of an investigator trained in the clinical sciences and possessing a degree in medicine (M.D., D.V.M., D.D.M., D.O.). It is usually conducted by physician-investigators working in a clinical department of a medical school or in a clinical division of an institute. In general, clinical research is applied research, intended to ameliorate disease in the near term. Traditionally, it is the clinical researcher who applies the scientific and technological skills acquired through basic research to the vital tasks of medicine.

Both basic and clinical biomedical research personnel are critical to the biomedical research endeavor because of the skills and perspectives they bring to their work. However, the training of, supply of, and demand for clinical investigators present different issues than those of basic biomedical research personnel.

Recruiting and Retaining Physicians for Research Careers

It is the view of many in the medical profession that the clinical investigator is the critical link between the laboratory bench and bedside. While the basic biomedical scientist is well versed in the processes and intricacies of individual biological subsystems, and may have better training in research methods and techniques, it is the clinician who sees the whole system and recognizes the clinical manifestations of the underlying disease process. Thus, research initiated by physician-investigators tends to be more health-related, in general, than that of Ph.D. biomedical scientists.

In recent years, there has been concern that the country is facing an insufficient supply of well-trained physician-researchers, as fewer medical school graduates enter research careers and apply for research funds. This prospect is of concern because of the expense of allowing a prolonged lag time between the acquisition of knowledge and technological skills, and their application to medical care.

Currently, NIH supports almost 90 percent of all postdoctoral training in clinical research. The number of physicians seeking research training has declined on average by more than 6 percent per year since 1975 while the number of medical school graduates has risen from 12,716 in 1975, to 16,347 in 1985.[17] [18] According to NIH, 47 percent of 5,680 individuals seeking postdoctoral research training in 1975 were holders of clinical degrees. By 1980, only 36 percent of 5,321 individuals seeking postdoctoral training held clinical degrees.[19] NIH cites several possible reasons for the decline in the number of physicians seeking research training. Young physicians may be discouraged from entering research careers because of the increasing difficulty of staying current in two fields (clinical and research). There may be too little exposure to research in medical school because of the competing demands of an increasingly overloaded curriculum. Young physicians, incurring a high degree of indebtedness after medical school, may not be willing to face the traditionally lower pay of research positions versus practice.

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[16] This definition is the one adopted by the Committee on National Needs for Biomedical and Behavioral Research Personnel of the Institute of Medicine, National Academy of Sciences.

[17] Institute of Medicine, *Personal Needs*, op. cit.

[18] Anne E. Crowley et al., "Undergraduate Medical Education," *Journal of the American Medical Association*, vol. 254, No. 12, Sept. 27, 1985, pp. 1565-1572.

[19] Thomas E. Malone, "Report on Recruiting and Retaining Physicians for Research Careers" (typescript), National Institutes of Health, 1983.

At the same time that interest in research seems to be declining among medical students, demand for faculty in the clinical departments of medicine remains strong, possibly because of the increase in professional fee income as a growing source of revenue. Fishman and Jolly have noted that the expansion in the number of medical schools over the past 30 years led to a greater than 25-fold increase in the full-time clinical faculty at American medical centers.[20] As of 1982, IOM reported that the market opportunities for clinical investigators continued to be favorable: Medical school faculties are still growing and providing places for young physician-investigators interested in research careers.[21]

However, after more than 30 years of continuous growth, there appears to be a decline in medical school enrollments that could continue as the college-age population declines. These declining enrollments could potentially reduce the demand for physician-investigators at medical schools, the principal employers of NIH-sponsored clinical researchers. Thus, although there is a recognized and widespread realization that the physician plays a critical role in clinical investigation, and current demand is fairly high, opportunities for this population could diminish.

Another factor that affects the demand for physician investigators relates to the sources of revenue for medical schools. The abundance of Federal support for biomedical research since World War II created a continuous demand for trained biomedical research personnel, and provided a sizable source of income for medical schools with active researchers on their faculties.

Although research funds are intended primarily for the conduct of research, they also enable medical schools to expand the size of their faculties, and support graduate students, research assistants, and fellows. Federal research support grew from 11 percent of medical school income in 1947 to nearly 30 percent in 1969.[22] However, in recent years, this proportion has diminished, as medical schools rely increasingly on other sources of support. In 1983-84, Federal research funds comprised only 14.4 percent of medical schools' restricted revenues.[23] The uncertainty of relying on competitive grants as a source of revenue, combined with a larger population in competition for limited funds has led medical schools to seek more reliable and controllable sources of revenue. Funds from professional fee income have grown at an annual rate of 25 percent between 1968 and 1981.[24] The contribution of professional fee income to medical school revenues is now 32 percent of total funds as compared to 12.2 percent in 1970-71.[25] More recently, research funds have become available from nongovernmental sources. As Jolly and his colleagues note in their 1985 report on medical school finances:[26]

> The growth of private, nongovernmental funding for health research and development is a phenomenon of rather recent origin. It may owe a part of

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[20] A.P. Fishman and H. Paul Jolly, "Ph.D.'s in Clinical Departments," *The Physiologist*, vol. 24, 1981, pp. 17-21.

[21] Institute of Medicine, *Personal Needs*, op. cit.

[22] National Academy of Sciences, Institute of Medicine, *Costs of Education in Health Professions* (Washington, DC: National Academy Press, 1974).

[23] H. Paul Jolly, et al., "U.S. Medical School Finances," *Journal of the American Medical Association*, vol. 254, No. 12, Sept. 27, 1985, pp. 1573-1581.

[24] Institute of Medicine, *Personal Needs*, op. cit.

[25] H. Paul Jolly, et al., "U.S. Medical School Finances," *Journal of the American Medical Association*, vol. 252, No. 12, Sept. 28, 1984, pp. 1533-1541.

[26] Jolly, et al., 1985, op. cit., p. 1577.

its growth to the investment tax credits legislated in the early 1980s for increases in research and development by industry and the rapid expansion of research investment by the pharmaceutical industry related to rDNA technology, a part of which involves medical school performers.

Effectiveness of Federal Programs

In 1984, IOM, in consultation with NIH, examined the extent to which NIH-supported graduate students have been successful in their pursuit of careers in biomedical research.[27] They reported that former NIH predoctorals have outperformed individuals receiving no direct NIH support in terms of several measures. More than two-thirds of the NIH-supported group completed their doctorates compared to less than 50 percent of those receiving no support. In addition, the NIH group were more likely to have received NIH postdoctoral support and become involved at later stages in their careers in NIH-sponsored activities. They were more likely to have applied for and received NIH research grants. Last, former NIH trainees have written more articles and have received more citations than their biomedical colleagues who received no support.

Establishing cause and effect in any program evaluation is difficult. The success of the NIH-supported group may be due to the assistance they received, but it might also be due to the higher levels of motivation and intelligence which caused them to be selected in the first place. If so, there was a selection bias from the start and this group might have achieved the various accomplishments without Federal support. Whether they would have been able to complete the Ph.D. without Federal financial assistance is the critical question. It appears that the likelihood of completion has, in fact, increased.

Summary

Consistent Federal support for biomedical research in terms of funding of research and training has produced both a substantial supply and demand for investigators. This has had a largely positive effect. It has created a steady-state system in which there have been no major surpluses or shortages of biomedical personnel. However, it is a large system that would be difficult to reduce in significant ways without major dislocations. Unlike many fields of science, there is an institutional feedback mechanism between NIH and IOM that ensures a periodic assessment of the status of biomedical research personnel. This represents, to some extent, informed decisionmaking in the implementation of research training programs. The current number of trainees is quite close to the number recommended by the IOM committee.

Virtually all biomedical investigators have completed training to the doctoral level. Nearly 60 percent of them go on to postdoctoral appointments, compared to 28 percent of the Ph.D. cohort in science and engineering in the aggregate. Allocation of Federal support to either predoctoral training or postdoctoral training is a method of fine-tuning that can potentially be used to control the supply of biomedical investigators. This mechanism is exploited only in the biomedical sciences.

There appears to be no short-term shortage of basic biomedical scientists, although there may be some temporary shortages of special personnel in biotechnology. As industry innovates in biotechnology, there will be temporary shortages of highly specialized biomedical research personnel, such as bioprocess engineers, molecular geneticists, and genetic engineers. In some areas of biomedical science, there may be a surplus of trained Ph.D. scientists. While some Ph.D. biomedical scientists may currently be having problems in obtaining academic appointments, there is evidence that the rate of growth in industrial employment and self-employment may partially compensate for the surplus. Academic employment has been increasing by more than 4 percent per year, industrial employment is increasing by 8 percent, and self-employment is growing the fastest, at nearly 25 percent. While the postdoctoral appointment has increasingly compensated for the lack of academic appointments, it is a short-term solution to the academic surplus that requires more extensive examination. Postdoctoral appointees, do, however, conduct significant and important research in U.S. research institutions.

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[27] Institute of Medicine, *Career Achievements*, op. cit., 1984.

There is, however, evidence that the Nation is facing a potential shortage of clinical investigators, as fewer physicians pursue research careers. As fewer physicians enter into research careers, the potential for a widening gap between the direction of basic biomedical research and the treatment of recognized disease states becomes greater. NIH has implemented fellowship programs to encourage medical students and new physicians to pursue research careers.

Table A-2.—Federal Manpower Legislation Pertaining to Biomedical and Medical Personnel

1930	*Ransdell Act*: created the National Institutes of Health.
1937	Amendments to the *Ransdell Act*: established the National Cancer Institute which established the first Federal biomedical research program.
1944	Amendments to the *Public Health Service Act*: grants authority to NIH for extramural research programs.
1963	*Health Professionals Education Assistance Act*: established matching grants to assist in the construction of teaching facilities for schools of medicine and health professions, in response to the aggregate physician supply concern. Initiated a student loan program.
1965	*Medicare/Medicaid*: created new demand for medical care, and further pushed the drive for increased biomedical research.
1965	Amendments to *Health Professionals Education Assistance Act*: extended the construction and student loan provisions of original act. Established grants to health professions schools that increase enrollments (capitation).
1966	*Allied Health Professionals Personnel Training Act*: authorized establishment of a health professions student loan revolving fund.
1968	*Health Manpower Act*: extended the construction, basic and special improvement grants program, student loans, and scholarship programs. Institutional grants determined on a capitation basis.
1971	*Comprehensive Health Manpower Training Act*: established four areas of authorization—construction grants for teaching and research facilities, capitation grants with an emphasis on certain curricular components, student assistance, and computer technology health care demonstration programs.
1972	*Emergency Health Personnel Act* Amendments: Public Health Service and National Health Service Corps Scholarships were established with awards contingent on agreement to serve in a shortage area.
1974	*National Research Service Award Act*: abolished and consolidated previous research training authorities under the Public Health Service Act.
1976	Amendments to the *Comprehensive Health Manpower Training Act*: capitation contingent on federally determined proportion of residencies in primary care.
1981	*Omnibus Reconciliation Act*: budget cuts in education in the health professions, elimination of capitation grants.

SOURCE: Office of Technology Assessment.

Appendix B: Responses to an OTA Survey on Information Needs Related to Minorities in Science and Eingineering

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The literature on the factors that affect minority participation in science and engineering is not nearly so well developed as that for women. To supplement the few comprehensive studies on this subject to date, OTA sent a questionnaire on "information needs related to minorities in science and engineering" to 40 recognized experts in the field. Respondents were asked to present their views as to the causes of and remedies for problems in minority participation in science and engineering; the effectiveness of existing intervention programs to promote such participation; and the need for further research, additional information, and policy actions. Responses received from 18 individuals are summarized below, by question.

1. What do you believe to be the principal factors that influence minorities' decisions to participate and continue in science and engineering careers? Are there special factors that discourage minorities from participating?

The negative factors most commonly mentioned by respondents were:

- lack of academic preparedness in elementary and secondary school (literacy and necessary science and mathematics courses);
- lack of role models, mentors and teacher encouragement;
- lack of parental support and encouragement;
- lack of peer support;
- inadequate career and academic counseling;
- lack of confidence and perception of self;
- financial strains; and
- lack of awareness of career opportunities.

Other negative factors included:

- societal emphasis on sports, rock stars, and "quickie" models of success rather than a slow and sequential model;
- loss of interest or motivation;
- poor study habits;
- lower educational and financial background (socioeconomic class standing);
- dry unimaginative teaching;
- lack of institutional commitment to minority students;
- declining number of qualified teachers and lack of in-service training opportunities for teachers;
- increasing remedial classes;
- identity problems (one respondent believes this is especially so for American Indians);
- lack of summer jobs in science/engineering;
- lack of cultural and society support for science;
- type and environment of undergraduate institution;
- lack of effective instructional programs to promote cultural awareness and development of bilingual skills (especially Chicano, Puerto Rican, and American Indian); and
- lack of transitional instructional programs for students with limited English language skills.

Positive factors for all minorities are:

- competence in the English language;
- early enrollment in math and science courses;
- continuation of math and science sequence in secondary school;
- basic interest in science and math;
- intervention programs;
- encouragement and support from mentors, family, and teachers;
- role models;
- positive input from peer group with high expectations;
- availability of financial resources;
- self-discipline;
- good study habits;
- continued success;
- challenge;
- good environment;
- intellectual gratification;
- opportunity to obtain research experience;
- second-generation college student (for blacks);
- awareness of careers and opportunities in science and engineering;
- starting salaries and possibilities for promotion; and
- one respondent said the perception of a science or math career as an avenue for "escape" from an undesirable environment.

2. Are there major gaps in information and understanding relative to the factors which influence minority participation in science and engineering? If so, please identify.

A majority of the respondents felt that more information is needed on the experiences of minority students who are successfully participating in science and engineering. No major study exists on how graduates succeed in completing science and engineering programs. Why not study those who made it, let them explain why, how, and where they came from before they completed a science or engineering degree? Study every member of several black, Hispanic, and American Indian science and engineering societies to determine what they have in common, and what their differences are.

We do not understand the *relative influence* of the various factors that affect the participation of different minority groups in science and engineering. Little attention has been given to differences in cognitive styles that might exist for different minority groups. Many pieces of data, otherwise "available," are not broken down by race and by sex, so that it is difficult to make full use of collected information.

Successful programs have not been evaluated to determine how they work, why they work, and what they have produced. Further research is required to develop new strategies and programs that will encourage minority students to pursue careers in science and engineering.

3. What new research initiatives would you recommend to help provide the needed information or understanding relative to the factors influencing minority participation in science and engineering?

One of the most frequently cited recommendations was the need to improve the quality of mathematics and science programs at the pre-college level, including improving basic skills. Improving the quality of teaching was also highly recommended, and a need was expressed for approaches that would motivate, up-date, and retrain inner-city school teachers. Guidance counselors should be retrained and attuned to current opportunities in science and math.

Research is needed on the outcomes of programs specifically designed to recruit and maintain minorities in science and engineering. We know relatively little about which programs have succeeded and why. Previously supported programs that have had a strong positive educational impact should be examined for possible reinstitution.

Financial aid is still crucial to enable minorities to attend and remain in college.

There is a need to track students through the educational pipeline; students who show an aptitude for science and mathematics as early as junior high school. Participants in pre-college special programs should be tracked for 10 years after high school graduation to determine the relationship between program participation and academic performance, retention in college and career choice. The relationship between career aspirations of minorities between grades K and 12 and their decision to participate in science and mathematics education should be examined.

Research on the effect of role models and early exposure to science on career choice is needed.

Current information should be made available, broken down by race and sex. More efforts are needed to sort out the relative weight of the different barriers to minorities' participation in science and engineering.

The whole web of cultural and social values should be examined in order to understand why Asians and Asian Americans as a group have successfully entered quantitatively based fields in disproportionately large numbers relative to their representation in the population, in spite of numerous barriers. We need to identify factors at work in the case of individual non-Asian minorities, who successfully enter science and engineering fields.

One respondent suggested the following additional studies: The family and educational backgrounds, and career pattern and experiences of minority scientists and engineers. Quantitative studies of high school students experiences in mathematics and science courses. The attitudes of teachers and parents regarding appropriate candidates for science/engineering. A study of guidance counselors' familiarity with opportunities for blacks in science and engineering. More systematic evaluation of intervention programs. A study of the impact of the availability of financial aid on career decisionmaking. A study of high school students' career awareness with respect to opportunities in science/ engineering.

As a final note, three respondents believed no new research was necessary. What is needed is action.

4. In the recent past, a variety of programs and policies have been initiated, on the Federal, State, local, and institutional level, to promote minority participation in science and engineering. How effective have the programs and policies with which you are most familiar been in achieving their goals? Can you cite specific examples of success or failure?

Three programs were cited most often as successes: The Mathematics, Engineering, Science Achievement (MESA) program of the Lawrence Hall of Sciences in Berkeley, CA; the Philadelphia Regional Introduction for Minorities in Engineering (PRIME) program; and the Resource Centers for Science and Engineering. The Atlanta University Resource Center's Summer Science Enrichment Program was also mentioned. Only a few of the respondents had actual knowledge of the programs; most relied on hearsay.

In terms of actual experiences one respondent stated,

> I created the first successful program to bring blacks into engineering in circa 1965-1968 at Oakland University, Rochester, Michigan. In 1973 I began a program to bring women into Engineering at the University of Virginia. We went from *zero* to the highest percentage of women in the Nation in five years.

Another respondent reported first-hand knowlege of the following minority programs sponsored by Federal agencies: Minority Research Initiation (MRI), Research Initiation in Minority Institutions (RIMI), Minority Biomedical Research Support (MBRS), Minority Access to Research Career (MARC), Research Center for Science and Engineering (RCSE), and the Minority Institutions Science Improvement

Program (MISIP). Of the preceding programs, only the Resource Centers were conceived and planned to be comprehensive in approach. Through the respondent's experience with the Puerto Rico Resource Center, the respondent concluded that the only effective way to upgrade science education for minorities was to follow a holistic approach in which resources are optimized to address different stages of the educational process. Most other programs tend to be targeted, rather narrow, and limited in scope.

The same respondent stated that the MBRS and MARC programs have a strong overlap in goals, but nonetheless have been extremely successful in encouraging and orienting students toward biomedical research careers. The National Science Foundation (NSF) should be encouraged to consider the possibility of creating equivalent programs in the physical sciences, mathematics, and engineering. The MRI at NSF has been particularly successful in starting young minority scientists in their research careers. Competition for research funds is so keen that without the MRI programs, many minority scientists might not be able to establish themselves as regular faculty members in research institutions. Lastly, the RIMI program has been crucial in providing infrastructure for research in minority institutions although the funds available are not sufficient to remedy the seriousness of the problem.

Other exemplary programs cited were: Project Act 101 (Drexel University), Project Yes (University of the District of Columbia), Southeastern Consortium for Minorities in Engineering (SECME), A Better Chance, Inc. of Boston, National Action Council for Minorities in Engineering (NACME), Phillips Academy, and the Andover-Dartmouth Urban Institute intensive 4-week summer mathematic program for secondary school teachers.

The most successful programs have been those with clearly defined goals; stable financial support and stable staffing; a range of support services; and strong ties to parents, professional societies, the local schools, and other community groups.

One respondent stated it this way: Most of the long-established programs are quite successful, but most suffer from inadequate long-term funding, inadequate long-term assessment, little funding for transfer of successful models, and the need to prove themselves over and over again. The Resource Centers were a successful program at NSF, but they are not being supported in 1985 because of the lack of long-term Federal commitment. The decision to discontinue the program was made independent of the fact that it works.

Another expressed disapproval:

> Most of the Federal, State, or local programs have not been the most effective use of resources. Programs have disappeared at the end of funding. Resources duplicated existing programs. California's investment in MESA and Washington's in the minority engineering effort, are examples of how to build results-oriented, long-term programs that have multi-sector support and work *with* educational institutions for the benefit of parents. Many of the old NSF programs were effective in training teachers, but they are ended.

5. What have we learned from these programs and policies; what specific factors appear to account for differences in relative effectiveness?

Evidence obtained to date from the many intervention programs indicates that women and minority students will do as well as white males when provided with quality education and support for their goals. The early identification of minority students with an aptitude for mathematics and science, followed by a long-term enrichment and motivation program, has been shown to be an effective approach.

Specific factors cited by one respondent as contributing to the success of such programs were:

- an effective liaison between primary and secondary educational systems and higher education;
- parental awareness and participation;

- length of enrollment in the pre-college program;
- adequate resources; and
- a career development component.

Activities with a large motivational content, where students are exposed to role models and to nontraditional ways of teaching science, were said to have a profound and permanent effect in encouraging students to continue careers in science. Special programs to train kindergarten to sixth grade teachers in the presentation and teaching of mathematical and scientific concepts, and the development of quantitative skills and scientific methods were cited as crucial if minority students are to be oriented toward science and mathematics programs in large numbers. Respondents stressed the importance of continuity in minority programs. They must be comprehensive and maintained over a sustained period of time.

One respondent stated that the principal lesson learned from the Resource Centers was that a systems' approach is crucial to establish a comprehensive and coherent plan to develop minority institutions into research centers and increase the number of students who go on to become research scientists and engineers.

Other factors cited were:

- hands on experience;
- strong directors and able, interested staff;
- opportunities for in-school and out-of-school learning experiences;
- community support;
- development of a peer support sytems;
- evaluation;
- long-term follow up; and
- careful data collection, and mainstreaming.

6. What additional information is needed to better understand the causes of success and failure in programs and policies that promote minority participation in science and engineering?

Most of the respondents felt that program evaluation is the most needed supplement to existing information. This includes evaluation of intervention programs and policies for promoting minority participation in science and engineering; all pre-college engineering, mathematics, and science programs; and curricula of primary and secondary systems attended by minorities compared to those attended by majority students.

Further study and support of the following was also suggested: The current and future role of predominantly minority institutions in the preparation of students for quantitative fields, the presence and role of minorities in arenas where major science policy issues and decisions are being made, successful efforts at the undergraduate level to recruit and retain minority students in quantitative fields, specific ways to effectively communicate with the minority community about the importance of science and its applications in their lives, and the availability of computers to minority students and the ways in which they are being instructed to use them.

Three of the respondents felt that no more information is needed, only action; the implementation of recognized successful programs in education.

7. What actions, if any, would you recommend Congress take to promote minority participation in science and engineering, or to develop a better understanding of the factors that influence minority participation?

Most of the actions recommended for congressional consideration fell into three main categories: The establishment and support of special programs for minorities in science and mathematics, strengthening the quality of mathematics and science education in general, and financial support for minority students.

Some of the types of programs cited as deserving of support were: programs to promote curriculum development in mathematics and science for minority students at the primary and secondary school level; programs that provide elementary and high school students with hands on exposure to science and engineering; programs that encourage minority scientists and upper level minority science students to participate in minority science education; community-based programs that utilize outside expertise, but maintain control within local schools; programs aimed at increasing the number of students completing Algebra 1 and Biology 1 by the 9th grade, and the number of students taking and completing 3 or 4 years of mathematics, science, and English by the time they receive their high school diploma; and the development of magnet schools for the education of students with a special interest in science. It was recommended that the Government provide summer enrichment programs for minority students with talent and interest in science and mathematics, and reestablish the Resource Centers program.

Associated with program support was the need to improve instruction in science and engineering in general. Pre-college science and mathematics instruction in urban schools needs to be improved with an emphasis on involving both sexes. There should be increased funding for research on effective teaching and learning of mathematical and scientific concepts and skills, with a reasonable proportion set aside to study populations at risk for low achievement on the fundamental cognitive and conceptual level. We should continue informing the very young of opportunities in science and engineering, and educating the educators. Finally mathematics and science education in general should be strengthened through special funding for equipment and teacher training.

Financial support for minority students was suggested via various means: Establishment of "congressional scholars in science and technology" (a comprehensive 3- or 4-year program of undergraduate support, research, and work experience to ensure that talented minority students will not be lost to science and engineering because they are unable to pay the cost of first-rate college training in these fields). Two-year scholarships could be awarded to a group of minority high school juniors, and to a comparable number of minority college juniors, who have demonstrated significant interest in and potential for successfully pursuing science or mathematics study at the next educational level. (Consideration might be given to targeting some of the proposed awards to students interested in pursuing science/mathematics teaching careers.) Financial support to students could be increased, *especially* support not involving loans. No-interest or low-interest college loans could be provided to students with strong mathematics and science backgrounds who agree to teach mathematics and science courses in economically disadvantaged communities. A federally guaranteed, low interest loan program could be established and specifically designated for minorities who indicate an interest in becoming scientists or engineers.

Some respondents recommended an examination of the Department of Education and NSF programs for minorities to determine their effectiveness, and the need for additional financial support. Continuity of successful minority programs should be the guiding factor in the determination of funding by Congress for minority programs, in their view. Such programs should be "mainstreamed" into the regular educational process, where possible.

A number of respondents called for a centralized organization to deal with the problems of minorities in science and mathematics. A national conference or hearing could be convened on minority participation in science and engineering. A commission could be established, composed of scientists and educators from the underrepresented groups as well as representatives from employers affected by the underrepresentation (e.g., universities, industry, national labs). A national office is needed, according to some respondents, to facilitate and conduct activities designed to increase minority participation in science and mathematics.

PART II

PREPARING FOR SCIENCE AND ENGINEERING CAREERS: FIELD-LEVEL PROFILES

Staff Paper

January 8, 1987

Science, Education, and Transportation Program
Office of Technology Assessment
U.S. Congress

The views expressed in this Staff Paper are not necessarily those of the Technology Assessment Board, the Technology Assessment Advisory Council, or of individual members thereof.

PREPARING FOR SCIENCE AND ENGINEERING CAREERS:

FIELD-LEVEL PROFILES

Introduction and Highlights

This Staff Paper is an addendum to Demographic Trends and the Scientific and Engineering Work Force, an OTA Technical Memorandum published in December 1985. The paper was produced in response to a request by the Committee on Science and Technology of the House of Representatives, to examine differences in the supply and demand of personnel across individual fields of science and engineering, and the sensitivity of these fields to demographic trends.

The document consists of a dozen profiles presented in five broad field categories: the physical sciences (**physics and astronomy, chemistry, earth and environmental sciences**); mathematical and computer sciences; the life sciences (**biological, health/medical, agricultural**); social and behavioral sciences (**psychology, economics**); and engineering (**chemical, electrical**). All profiles include trend data on enrollments, degrees conferred, and employment by sector and primary work activity. Detailed information is also given on preparation for careers in science and engineering of three groups of people: women, minorities, and foreign nationals. The time period covered by most of the descriptive statistics is 1960-86.

The paper illustrates differences in the education and entry-level employment of degreed science and engineering talent, especially characteristics that are obscured by aggregated data analysis. A brief narrative introduces each broad field section and a series of graphs and charts accompanies each profile. In addition, a note on data precedes the profiles; this note provides an overview of data sources and explains important idiosyncrasies of their reporting.

Each field profile has been written as a self-contained section. As the individual field or discipline is a smaller, more uniform population than the science and engineering work force as a whole, each field tends to have a characteristic pattern of education and employment. Analysis at the level of the field can improve understanding of how different market forces, demographic factors, and public policies interact to affect the supply of and demand for scientists and engineers. The following are highlights of a disaggregated analysis. Such analysis augments generalizations about the science and engineering work force as a whole.

1. **The smaller and more specialized the scientific field being studied, the less predictable are changes in the factors that affect demand, such as scientific and technological advances, shifts in Federal funding priorities, and industrial research and development (R&D) spending.** Small changes in the total supply of scientists and engineers can mask significant adjustment within and among fields. The total number of Ph.D.s awarded in science and engineering rose by 7 percent between 1980 and 1985. During this period, physics Ph.D. awards rose 10 percent and mathematics Ph.D.s declined almost as much. Both were overshadowed, however, by an increase in computer science Ph.D.s of 35 percent. The relationship between fields, especially mathematics and computer science, is critical for interpreting these degree trends.

2. **Demographic trends play very little, if any, role in the supply of scientists or engineers in individual fields or in one field relative to another.** Some demand factors affect all science and engineering, such as the general health of the U.S. industrial economy and the level of Federal R&D funding. Although the national economy may be healthy and the overall demand for scientists and engineers strong, a downturn in the oil industry will quench the demand for petroleum engineers. Similarly, a shift in emphasis within Federal R&D funding, even though overall R&D funding remains stable, can significantly change the demand in particular fields while not changing the total demand for scientists.

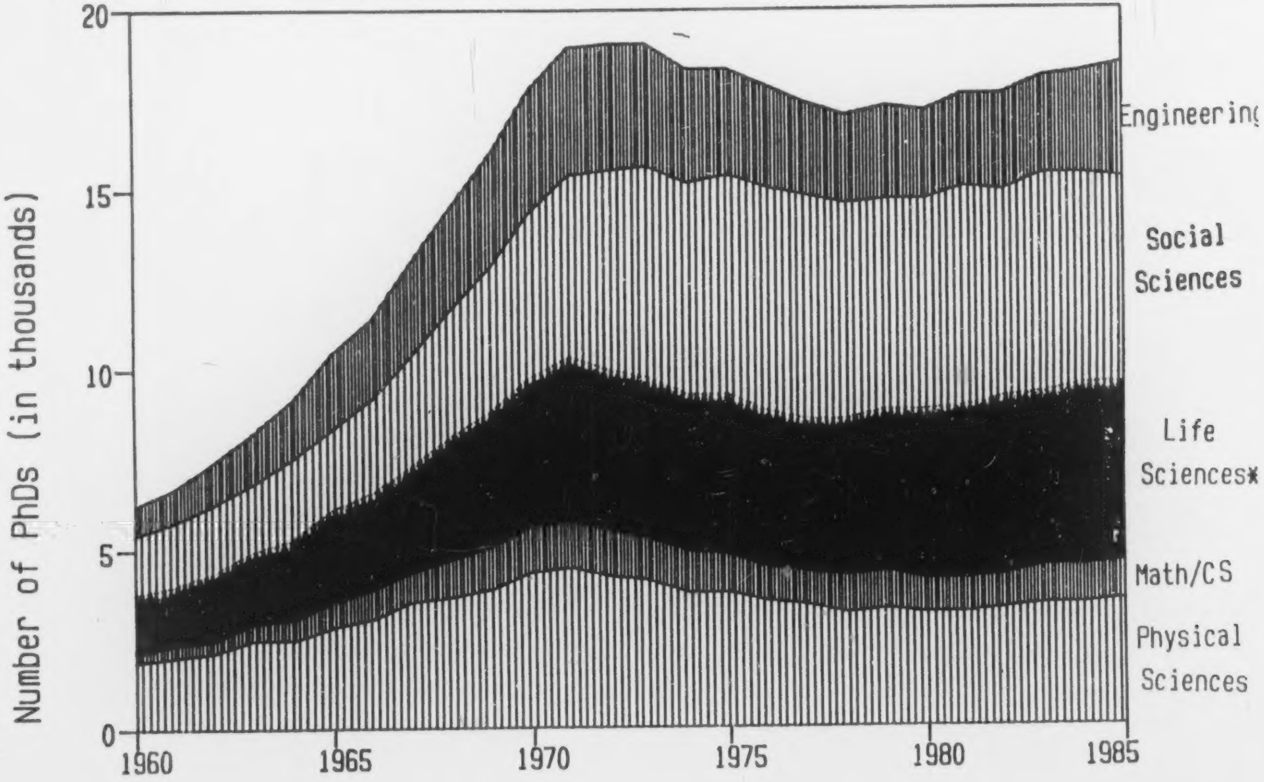
3. **Graduate enrollments and degree awards are highly responsive to small shifts in Federal education and research support.** In academic sciences such as mathematics, the life sciences, and astronomy, Federal Government support dominates. In industry-oriented fields, students respond quickly to changes in the job market. For example, unprecedented growth in the U.S. computer and semiconductor industries in the late 1970s generated a large demand for electrical engineers and computer specialists, which was answered quickly with an equally unprecedented boom in undergraduate electrical engineering enrollments.

4. **Breadth of employment brings stability to a field.** Chemical and mechanical engineers work in many different industries and can move among them. Petroleum engineers, on the other hand, depend almost exclusively on the petroleum industry for jobs. Diversity of employment may also tend to encourage broader education and a more versatile and mobile work force. Prospects for employment, not demographics, may be the key factor in maintaining the supply of talent in a field.

5. **Labor markets adjust to supply-demand gaps. The Federal role in alleviating potential shortages of technical personnel appears limited to assistance for education and retraining.** Shortages and surpluses are most likely to arise at the level of the specialty or skill rather than the field, and are more likely at the level of the field than for science and engineering as a whole. While petroleum geologists are currently over- supplied, hydrologists are in demand to address rising concern over groundwater supplies and quality.

6. **The labor market adjusts to supply-demand gaps in two ways: individuals already in the work force change jobs and, after a lag, the number of degrees awarded in that field changes.** Students are likely to shift specialties within a field before they shift fields, and more likely to shift fields than opt out of science or engineering altogether. Students may prolong their education until a poor job market improves, or hasten entry into a good job market without completing graduate work. Engineers can often shift to

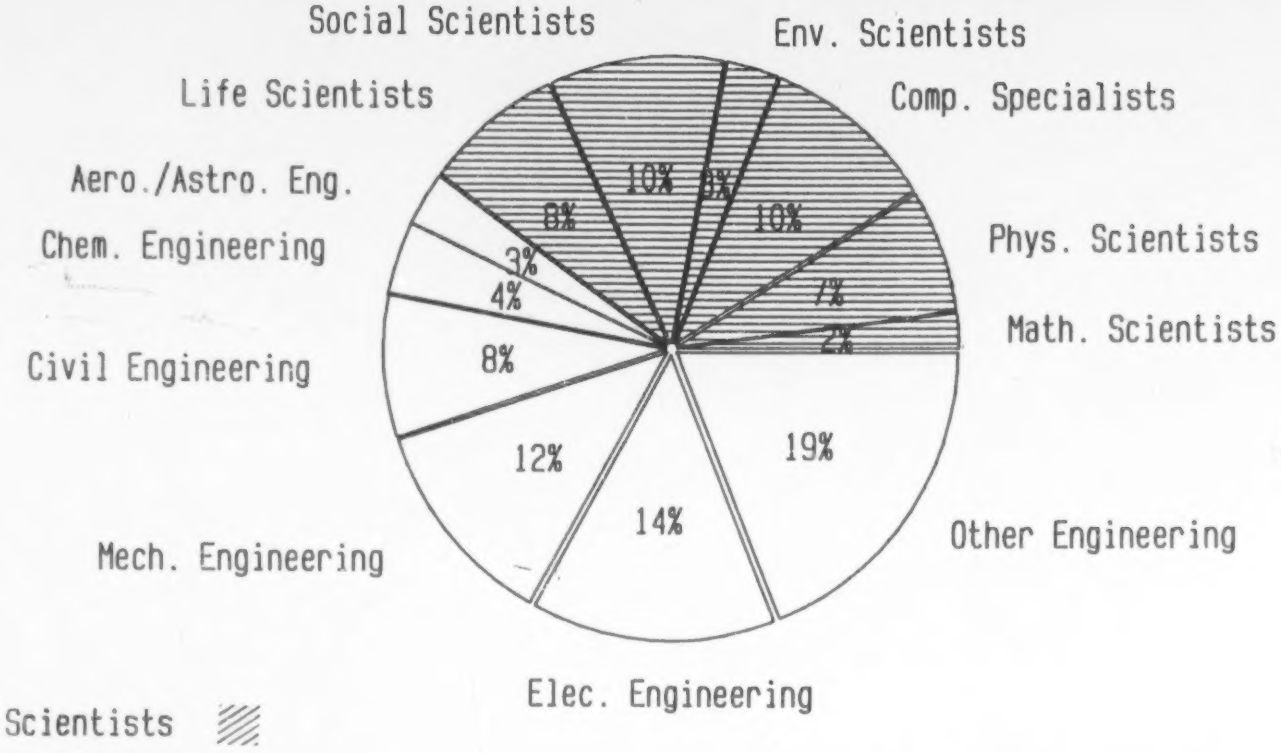
Growth in S/E PhDs by Broad Fields, 1960-1985



*except Health

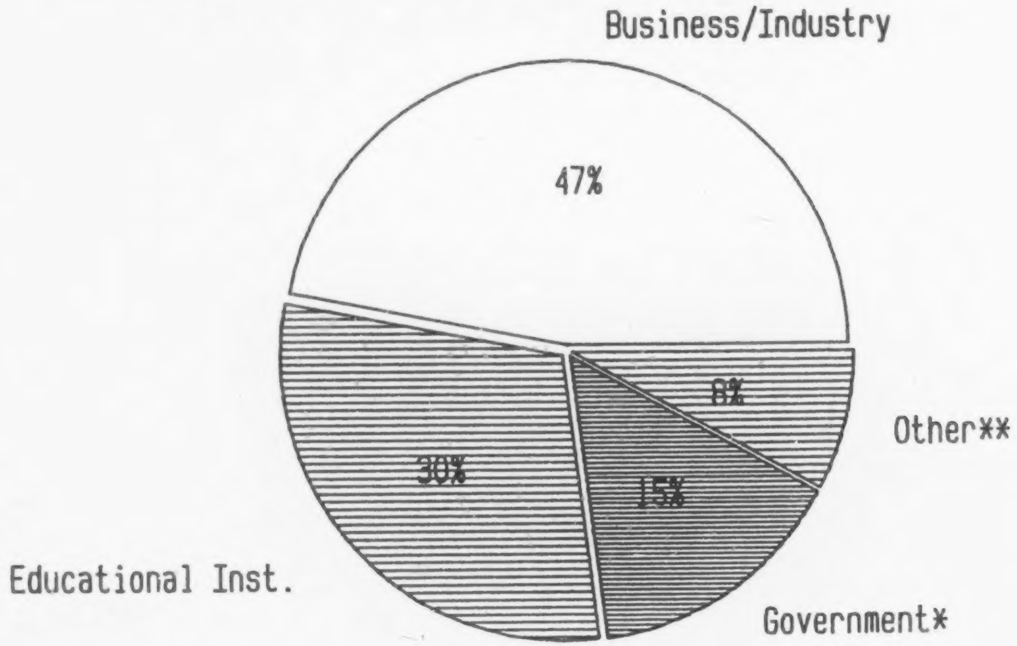
Source: NRC

U.S. Scientists/Engineers by Field, 1986



Source: NSF, 1986

Scientists by Sector of Employment, 1986

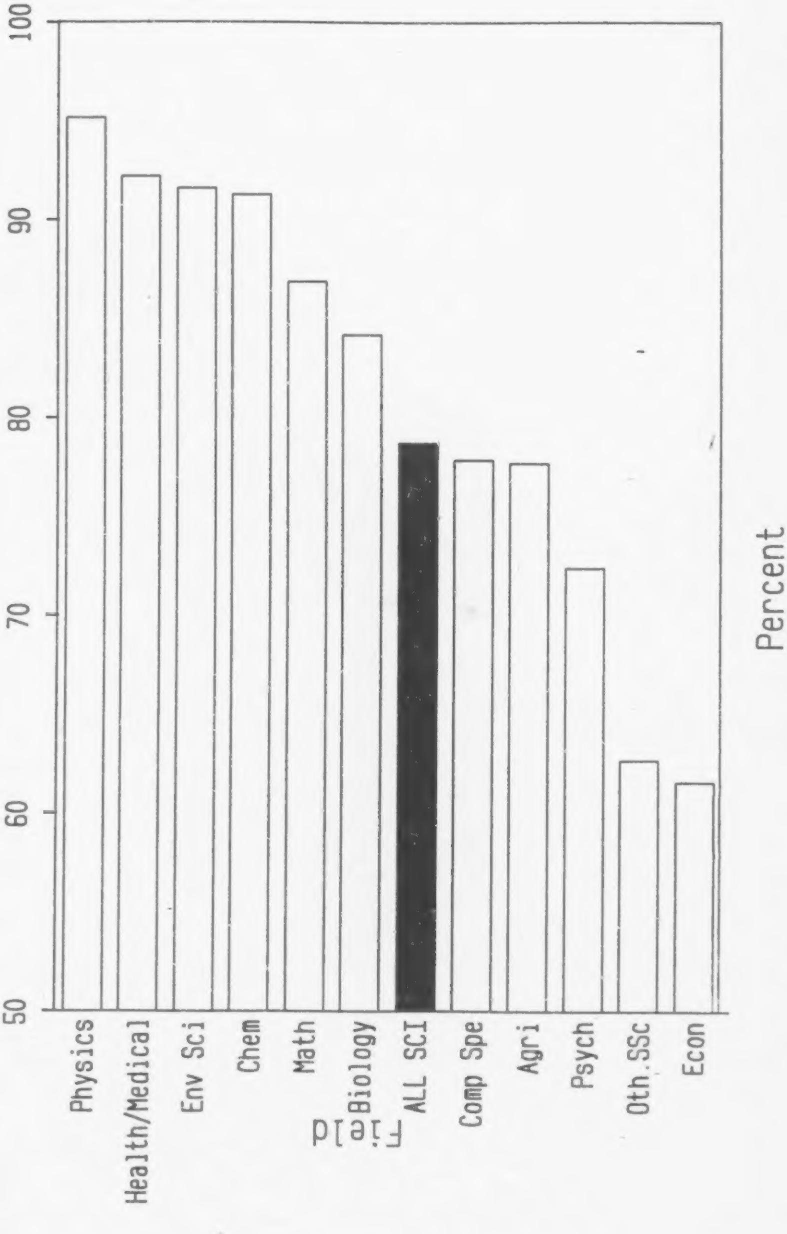


includes Federal,
State/Local,
and other gov't.

**includes nonprofit
institutions,military,
and all other, and no report

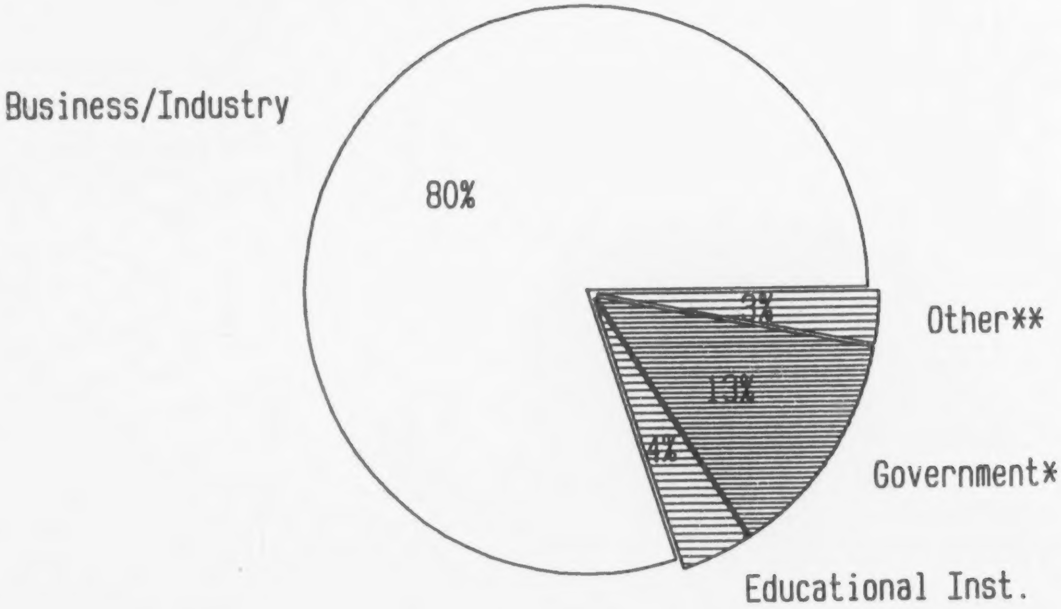
Source: NSF, 1986

Employed Scientists in S/E Jobs, 1986



Source: NSF

Engineers by Sector of Employment, 1986



includes Federal,
State/Local,
nd other gov't.

**includes nonprofit
institutions, military,
and all other, and no report

Source: NSF, 1986

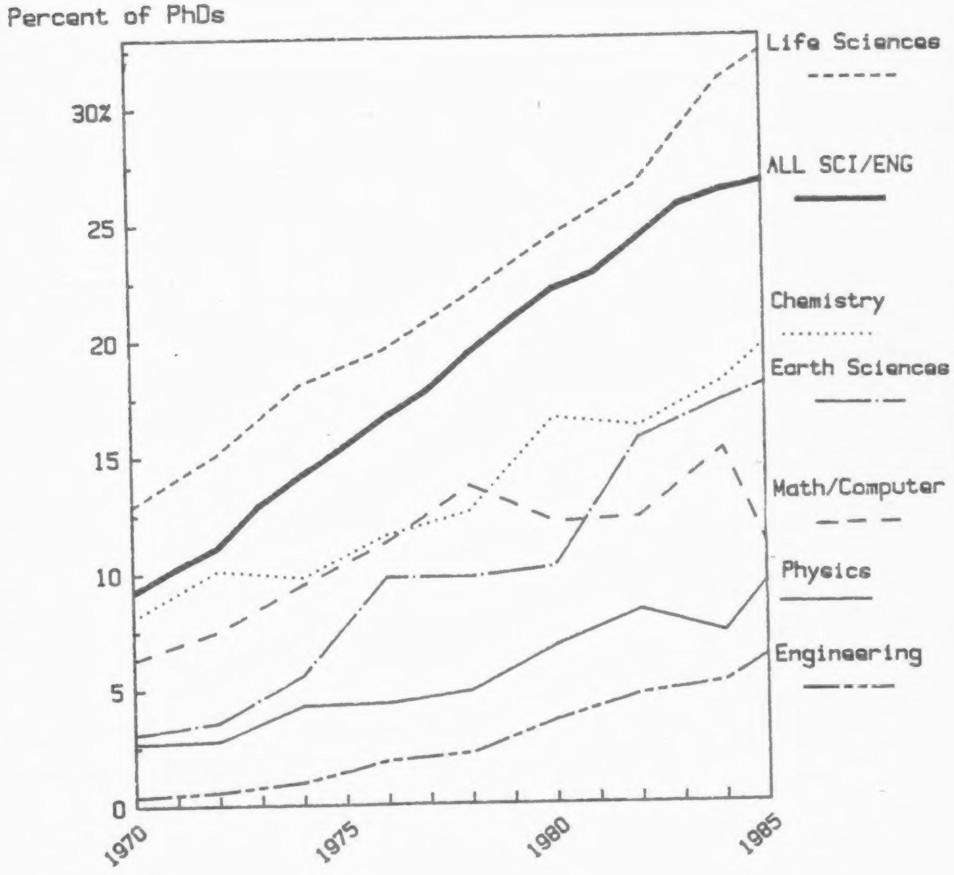
meet changing skill requirements and job opportunities; few scientists (notably, in mathematics and physics) emigrate to other fields. This mobility stems both from a recognition of individual versatility (in pursuing research problems and funding) and the continuing oversupply of Ph.D.s relative to opportunities for research positions in one's original field.

7. **Recent engineering graduates seem well able to shift to meet new challenges; scientists are flexible to a lesser degree because of their longer and more specialized professional training.** Engineering students can be more responsive than science students to current market conditions because of the relatively short time lag between selecting an engineering specialty, sometimes as late as the junior year of college, and obtaining the professional credential of a bachelor's degree. The total number of B.S. degrees awarded in engineering doubled between 1975 and 1985. Computer and electrical engineering exceeded this rate and added over 15,000 to the work force during this period.

8. **The scope of fields and the boundaries between them are constantly changing.** Whether a researcher in laser optics should be counted as a physicist or an engineer is a matter of judgment rather than hard-and-fast definition. New interdisciplinary fields emerge from cross-fertilization between subfields or as spinoffs from a fruitful line of research in an established discipline. Categories tend to lag the reality of emerging disciplines. This makes it especially difficult to track disciplines in their formative years. Reliable data on computer scientists and materials scientists, for instance, are just beginning to be available.

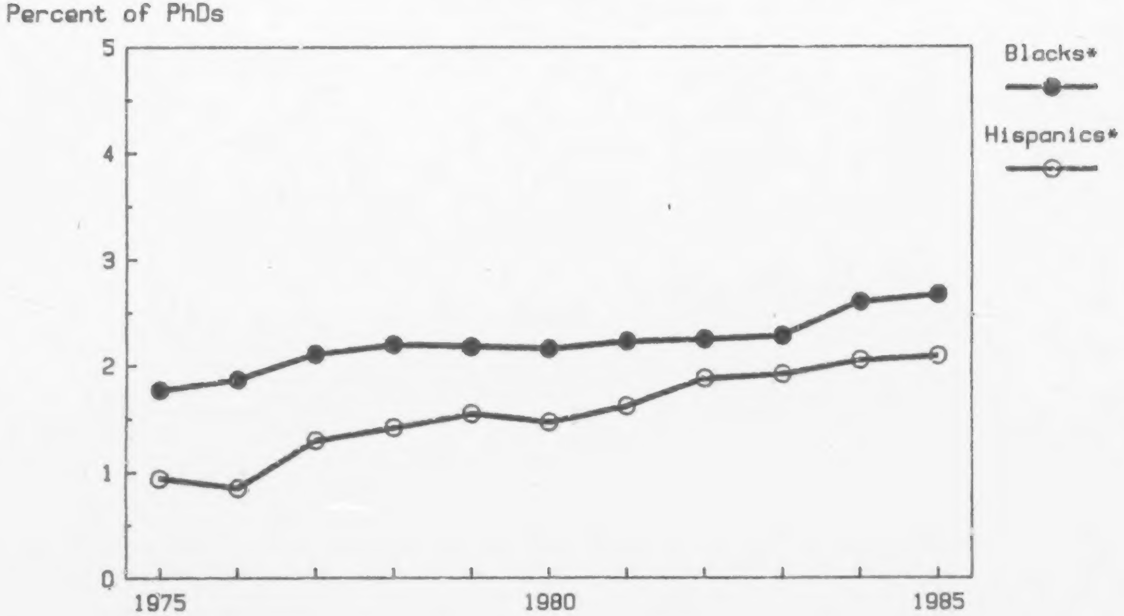
9. **The level of women's participation in science and engineering varies significantly by field.** Women have made gradual gains over the past 15 years in science and engineering, though increases have slowed in recent years. In 1985, their share of science and engineering Ph.D.s declined for the first time, although the decrease was all in the social sciences while Ph.D. awards to women in engineering, life, and physical

Women as a Proportion of PhDs
All S/E Fields, 1970-1985



Source: National Research Council

Blacks and Hispanics
as Proportion of Science/Engineering PhDs
1975-1985



*Percent of U.S. citizens + Foreign. Perm. Visa

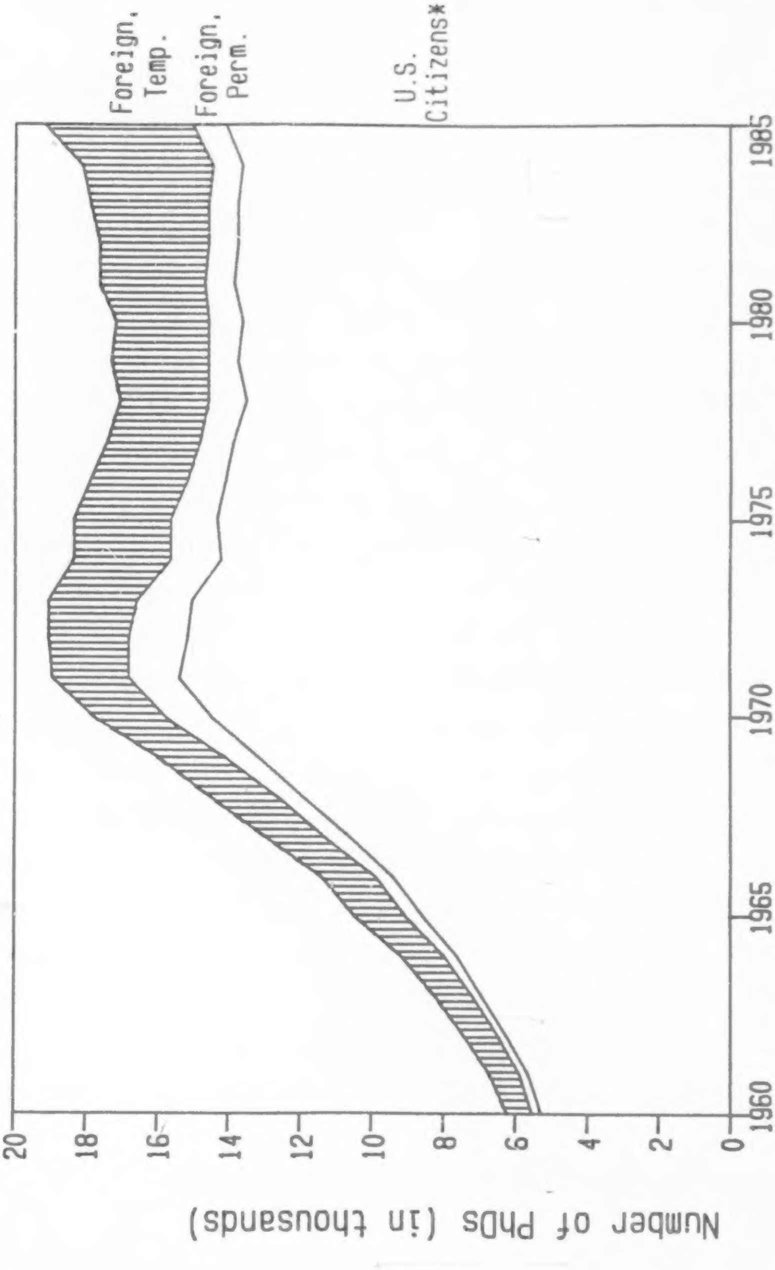
Source: National Research Council

sciences continued upwards. Women receive two out of three psychology bachelor's degrees and over half of psychology and health sciences Ph.D.s, but only 5 percent of physics Ph.D.s and 7 percent of engineering Ph.D.s. Among graduate students, women are twice as likely as men to be in the life sciences or social/behavioral sciences. In engineering, women tend to concentrate in industrial, chemical, petroleum, and electrical engineering. In all fields, women are more likely than men to be unemployed, underemployed, or working part-time; they are also paid less than men with equivalent experience and credentials. In colleges and universities they are less likely to be tenured or on the tenure track. Gender-stereotyped career expectations and differential treatment of women in traditionally male fields continue to deter their participation.

10. **Blacks, Hispanics, and American Indians are affected by a variety of socioeconomic factors that lead to weak academic preparation for a science or engineering major and difficulty remaining in the science and engineering pipeline.** Black participation has been chronically depressed in science and engineering. They are more underrepresented than Hispanics or American Indians and have made fewer gains over the past five years. In all science and engineering fields and at all junctures in the educational pipeline, blacks are the least likely to go on for further education. Less than 10 percent of employed black scientists have a Ph.D., compared to nearly 20 percent of white and 30 percent of Asian scientists. Blacks are less than 2 percent of employed engineers and receive only 2 to 3 percent of B.S. degrees in all engineering specialties, showing a slow but steady increase over the past ten years. Hispanics and American Indians have shown a similar slow but steady increase in their share of B.S. engineering degrees.

11. **Despite their minority status, Asian-Americans have attained a strong presence in science and engineering and continue to make rapid gains.** Asians continue to outpace other minorities as well as whites in science and engineering participation. Most Asian scientists and engineers, if not foreign citizens, are foreign-born or first-

S/E PhD Awards by Visa Status, 1960-1985



*includes unknown citizenship

Source: NRC

generation immigrants. The high profile and rapid gains of Asian scientists and engineers are skewed towards engineering, the mathematical and computer sciences, chemistry, and physics. The most rapid growth is in engineering. There are twice as many employed Asian-American engineers as there are Asian-American scientists; one-third of the science and engineering Ph.D.s awarded to Asian-Americans are in engineering, compared to just over 10 percent for Hispanics, less than 10 percent for whites, and less than 4 percent for blacks. Asians are more likely to continue on for higher degrees than any group.

12. **The increasing presence of foreign nationals is most visible in academic engineering.** Foreign nationals are about one-third of all engineering graduate students, more than 40 percent of full-time graduate students, and just under half of recent Ph.D.s. A paucity of American Ph.D. engineers has made universities particularly dependent upon new foreign Ph.D.s to fill faculty teaching and research positions. The high profile of foreign nationals among engineering graduate students, teaching assistants, and faculty raises questions about the quality of teaching in, and attractiveness of engineering for, American students. Foreign students have received a steady 7-9 percent of B.S. engineering degrees since the mid-1970s. In the sciences, foreign students are approximately 15 percent of all graduate students, but the proportion varies widely by field. In 1985, foreign students were much more likely than American students to be pursuing full-time graduate work. Most foreign graduate and postdoctoral students hold temporary visas. About half of graduate foreign engineers stay on to work in the U.S., at all degree levels.

A NOTE ON DATA

The field profiles that follow are based on sources that specialize their data analysis and reporting in various ways. This inevitably leads to inconsistencies in definition and methods of counting, be it students enrolled, degrees granted, or scientists and engineers employed. There has been no attempt to reconcile these differences. If estimates differ, this document reports the range and cites the sources. Where systematic differences exist that render one source preferable to another, that source has been used.

The main primary data sources on scientists and engineers are the National Science Foundation (NSF), Department of Education's National Center for Statistics (NCS), the National Research Council (NRC), the Bureau of Labor Statistics (BLS), the Bureau of the Census, and professional societies. For degree data, NCS provides the only time series at the bachelor's and master's levels; NSF reorganizes these data for reporting purposes. NRC data are the best at the doctorate level. NSF data begin in 1960; some NRC data go as far back as the 1920s.

Definitions

Some definitions are in order. Foreign nationals can be broken down into those on temporary and those on permanent visas. The latter are equivalent in status to U.S. citizens, and few in number. Most foreign nationals are students or professionals on temporary visas. Many of these protract their stay in the U.S. for several years through extensions of visas as students; a minority go on to gain permanent visa status.

Minorities fall into two distinct groups. The first includes blacks and Hispanics who are underrepresented in science and engineering relative to their proportion in the U.S. population. They have made few or no inroads into science and engineering over the past decade. The numbers of blacks and Hispanics are modest, while the miniscule numbers of American Indians preclude analysis. Asian-Americans, on the other hand, earn science and engineering degrees at a rate above the national average and have made significant gains in earned degrees and in employment.

There are significant differences among minority men and women and among minorities of different national origin, especially among the many Asian cultures. Quantitative analysis of these differences is still limited, however, and will not be discussed in depth in this paper.

Employment

The most comprehensive estimates on employment come from NSF and BLS. BLS reports employer-based data, whereas NSF uses characteristics of the employee: field of highest degree, field of primary work, and self-identification. NSF reports not only employment, unemployment, and underemployment*, but also the type of work that employed scientists and engineers do. NSF reporting generates three groups:

- the total science and engineering work force (including the employed and unemployed);
- employed scientists and engineers (about 98 percent of the total work force, as scientists and engineers have a very low unemployment rate); and
- employed scientists and engineers working in science and engineering jobs.

Discussion and data in this report generally refer to the last group, employed scientists and engineers currently employed in science and engineering jobs (primarily R&D,

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* NSF's definition of underemployment includes those who are involuntarily in non-science or engineering jobs or working part-time but seeking full-time employment. NSF adds unemployed and underemployed rates to define an "underutilized" segment of the work force. In 1986, 6.5 percent of scientists and 2.3 percent of engineers were "underutilized."

teaching, consulting, R&D management, computing, production, and inspection, according to NSF definitions). This is the active science and engineering work force. Nearly all employed engineers, but only about three-quarters of employed scientists, are in the active science and engineering work force.

Nearly all engineers are employed in science or engineering, with little variation by subfield. For scientists, however, the proportion employed in science or engineering jobs varies widely, from over 95 percent for ocean scientists and physicists to less than 65 percent for economists. Overall, 22 percent of employed scientists are working outside of science or engineering. These people constitute a reservoir of talent. This may reflect excess supply, underutilization, or demand which pulls scientifically-trained people into non-science jobs. It should be noted that the definition of a science or engineering job is open to liberal interpretation and subject to the vagaries of self-reporting. As a result, NSF employment data may mask people fulfilling several responsibilities, as well as those not directly working in science or engineering but using their technical training in their work.

Preliminary 1986 estimates of employment and work activity provided by NSF are used in the present profiles. NSF's Division of Science Resources Studies maintains the Scientific and Technical Personnel Data System (STPDS) to report national characteristics of the U.S. science and engineering work force in 27 fields. NSF publishes these data biennially; the 1986 data included here will be published in mid-1987. The STPDS consists of a model that projects changes in the science and engineering work force using field-specific historical growth rates. In addition, several special surveys are conducted, the results of which are used to identify significant deviations in historical growth rates among the fields and characteristics of each. Where appropriate, survey results are incorporated into the STPDS model.

Many professional societies collect extensive data on education, degrees, and employment. In some cases this supply and demand information is limited to individual or institutional members, while in others data collection spans the entire field. Professional society data in engineering and physics, for example, are both more current and perhaps more accurate than Federal agency data. Source and data idiosyncrasies are discussed below.

Physical Sciences

Professional societies compile detailed degree and employment information in physics, chemistry, and the geosciences. American Chemical Society data correlate well with Federal sources; American Institute of Physics degree figures are consistently higher by as much as 25 percent. The earth and environmental sciences have been treated differently over time and by different sources. The American Geological Institute collects data on enrollments and degrees by subfield of geoscience.

Mathematical and Computer Sciences

Computer science is still closely linked in theory and tools of research to the older field of mathematics. Before 1980, combining data into a single reporting category, as NRC has done for research support, may provide a more accurate picture of supply and demand characteristics than do the separate accounts used today.

Reliable data on the separate field of computer science begins around 1980. Data on computer science degrees are uncertain and inconsistent, principally because the relative youth of the field means that most practitioners earned their highest degree in some other field. In addition, there are discrepancies in categorizing mathematics, computer theory, computer and information science, and electrical/computer engineering degrees.

Estimates of the computer science labor force are only slightly better than educated guesses. There is no accepted definition of a computer scientist. NSF and BLS each report about 450,000 in the occupational category "computer specialists," although their estimates are based on independent definitions and data. NSF "computer specialists" include self-identified computer and systems analysts as well as computer scientists. Consequently, these estimates significantly overstate the actual number of computer scientists, as the bulk of "computer specialists" are systems analysts. There are no hard and fast rules for distinguishing between someone who uses and maintains computer systems and a computer scientist, or between a senior programmer and a systems analyst. Computer programmers and operators are reported separately. NSF is revising its definition of computer scientist.

NRC reports the 1985 computer science Ph.D. labor force — those who have received doctorates in computer science — to be 3,100 strong. However, the number of Ph.D.s working in computer science is much larger, 13,500 in 1985 (unpublished data) because so many scientists and engineers with Ph.D.s in other fields have migrated into the young and booming field of computer science.

The Computer Science Board, consisting of the chairmen of university computer science departments, has sponsored surveys of academic computer science and engineering research and graduate education since the early 1970s. Similarly, the American Mathematical Society annually collects data on mathematics faculty, employment, graduate enrollments, doctorate awards, and research and education support. The Conference Board on the Mathematical Sciences, an umbrella organization, also undertakes special data collection and analysis with outside project support.

Life Sciences

Data problems are particularly vexing in the life sciences. A consistent taxonomy of fields does not exist. The NSF's employment and activity estimates of life scientists do not permit easy comparison with its data on life science doctorate degrees. NRC's classification of life science Ph.D. fields differs from the NSF classification. Many of the Ph.D. specialties have no common undergraduate program base, making it difficult to track undergraduate and graduate degree trends.

This lack of consistency is unfortunate. The life sciences constitute a large field: one in five of all scientists in science and engineering positions in 1986 are life scientists. In addition, the life sciences receive large amounts of Federal research and development (R&D) funds. Of the more than $5 billion in Federal obligations to universities for R&D in 1983, the life sciences received over half, most of which was awarded by NIH. Lastly, the life sciences as research fields are considered to be especially robust with theoretical and empirical developments emerging at a fast pace.

The profiles of the life sciences presented here have been structured to be consistent with the work force and activity classification system used by the National Science Foundation. NSF divides the life sciences into three groups — biological sciences, agricultural sciences, and medical sciences. Several implications of this should be noted. The medical sciences include research specialties and work activities in the health and medical fields not directly involved in patient care. The agricultural sciences do not count agricultural economics, which is considered a social science when NSF reports doctorate data. Lastly, in order to be more or less consistent with NSF's work force estimates, we consider in this paper certain Ph.D. degree specialties included as biological sciences by NRC as medical/health specialties.

A related but different approach developed by the Committee on National Needs for Biomedical and Behavioral Research Personnel of the Institute of Medicine deserves mention. Responsible for making recommendations concerning the allocation of training awards under the provisions of the National Research Service Awards Act of 1984 (Public Law 93-348 as amended), the Committee produces a well-respected biennial report that addresses the need for biomedical and behavioral research personnel, the specialties requiring additional personnel, and the kind of training required. The Committee analyzes trends and makes its training recommendations using a field classification that organizes doctorate specialties into clinical science, basic biomedical science, behavioral science, health services research, and nursing research. In doing so, the Committee has assembled enrollment, degree, training, and employment data covering a 20-year period.

Finally, the Committee has devised novel methodologies for examining the supply and demand issues associated with these fields. It provides important information concerning the outlook for psychologists who constitute the core of its broad field, "behavioral sciences." The Committee's analysis of the basic biomedical sciences is an important contribution to understanding the dynamics operating in research specialties of primary concern to NIH.

Social and Behavioral Sciences

Comparing degree and employment data turns on what counts as a social science. Although economics and psychology are the largest subfields and are typically reported separately within the broad category of "social sciences," fields such as "urban studies" or "history" are arbitrarily included or excluded by data-collection organizations. The criteria used by NSF and BLS to estimate employment yield predictable disagreements. A psychologist employed as a computer scientist is, according to BLS, a computer scientist. NSF will count that same person as a psychologist if he or she holds a psychology degree and identifies himself or herself as a psychologist. Another data source is the American Psychological Association, which collects extensive data on the employment characteristics of its members.

Engineering

Accurate estimates of the size of the work force, or the proportions in different engineering specialties, are difficult to come by. BLS and NSF data on the engineering work force have consistently diverged, with BLS estimates historically higher than NSF's. In recent years, this pattern has been reversed. A related problem exists with engineering technology and technician degrees. NCS reports four-year technology degrees separately; the Engineering Manpower Commission (EMC) of the American Association of Engineering Societies provides more current reports on Bachelor of

Technology and engineering bachelor's degrees. Associate degrees are reported by both NCS and EMC, but the numbers do not match. The American Electronics Association, an industry organization, does occasional data collection and projections of employment trends in electrical engineering based on employer estimates.

PHYSICAL SCIENCES

The physical sciences encompass physics and astronomy, chemistry, and the earth and environmental sciences. These fields are more different than they are alike in where scientists are employed, the work they do, and the factors driving the demand for new researchers. Research physicists and astronomers depend primarily upon Federal research and development (R&D) support funneled into universities and national laboratories. In chemistry, basic university research is overshadowed by industrial R&D, which employs large numbers of R&D chemists at all degree levels, particularly Ph.D.s. Environmental sciences (comprised of earth, atmospheric, and ocean-science specialties) is a small field, with a core of geologists dependent upon the economic health of the oil and mining industries and a collection of interdisciplinary researchers responding to environmental R&D priorities.

Generally, undergraduate degrees in the physical sciences have risen slowly but steadily since 1975. Graduate enrollments declined rapidly in the early 1970s, stabilized through the late 1970s and early 1980s, and have increased slightly but steadily since 1982. There is a risk of oversimplifying career patterns of physical scientists, yet there are two primary paths: physical scientists at the doctoral level are employed primarily in research and teaching, and baccalaureate and master's graduates are employed in a variety of jobs and fields. Young scientists respond both to the employment market of a field and the more volatile demand for particular specialties and skills. Growth in graduate enrollments and the number of Ph.D.s conferred, especially in physics, is due almost solely to increases in foreign students.

A continuing oversupply of physicists relative to physics research opportunities has made a Ph.D. and several years of postdoctoral experience necessary preparation for a research career. Students have continued to enter physics despite the dearth of research opportunities because of the proven ability of bachelor's and Ph.D. physicists to move into other science and engineering fields. Astronomy is a small, university-based, basic research field, with near-total dependence on Federal support, but a theoretically challenging science that attracts many good students. In 1975, the astronomy community began discouraging entry of students into the field and diversifying graduate training to increase the job mobility of new astronomers.

Industrial and academic demand for research chemists has been relatively stable, with increasing emphasis on a graduate education for an industrial R&D position. The preferred entry level degree for earth scientists is the master's; there is smaller demand for basic researchers in this field. Many earth scientists are employed in the petroleum and mining industries, which are buffeted by business cycles and resource policies.

Physics and chemistry students prolong postdoctoral appointments during periods of sluggish demand. Unemployment is low among Ph.D. physical scientists, higher for recent bachelor's and master's graduates. Within each of these fields, however, shortages and surpluses occur for specific research specialties. Thus, there are current surpluses of new graduates in particle physics and petroleum geology, and at the same time shortages in optical physics and geochemistry. In some instances, there is a continuing mismatch between supply and demand, as in the continuing overproduction of particle physicists and theoretical physicists relative to research opportunities; other mismatches are transitory, such as the cyclical demand for geologists in oil industry exploration and R&D.

Women and non-Asian minorities are consistently underrepresented in the physical sciences. They receive only a small share of graduate degrees, particularly in physics, and an even smaller share of faculty positions.

PHYSICS AND ASTRONOMY

Employment

- There are 40,000 to 70,000 employed physicists and astronomers in the United States.[1] The vast majority are employed in science and engineering (S/E) positions. These figures include astronomers, who represent about 10 percent of the total.
- Of physicists and astronomers working in S/E positions, most are employed by educational institutions, lesser proportions by industry and the Federal Government.[2]
- The primary work activity of physicists and astronomers employed in S/E is research and development; almost one-half of these are doing basic research. Another one-quarter are in various management positions and about 20 percent are engaged primarily in teaching.[3]
- There is a surplus of Ph.D. physicists relative to the number of physics research slots. This surplus is highly mobile and employable; more physics Ph.D.s are working in other fields than is true for any other science.
- Of employed Ph.D. physicists, one-half work in academia. The rest are divided almost equally between industry and government (including national labs).[4]

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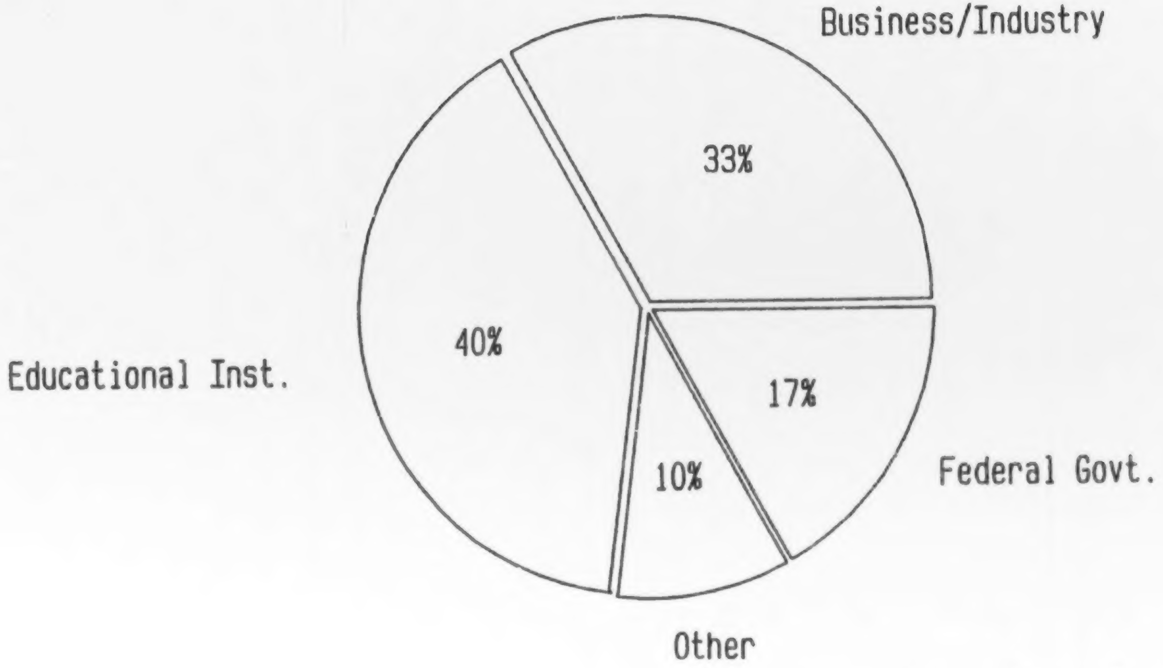
1. Estimates of employed physicists and astronomers vary widely. For example, in 1985 the Bureau of Labor Statistics reported 40,000, which included 13,000 teachers. The National Science Foundation's preliminary 1986 estimate is 70,800. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Table B-1, unpublished data.
2. Ibid, Table B-13.
3. Ibid.
4. National Science Foundation, Characteristics of Doctoral Scientists and Engineers in the United States: 1983, NSF 85-303 (Washington, DC: 1985), p. 19, Table B-5.

Where Physicists Work, 1986



SOURCE: NATIONAL SCIENCE FOUNDATION

Education and Supply

- The number of baccalaureate physics awards dropped rapidly through the 1970s, but has turned around and increased steadily since 1980. A smaller proportion are going on to graduate study; about one-half of baccalaureate physicists continue with some kind of graduate study, down from 60 percent 10 years ago. However, the decline is due to those changing fields; one-third of physics bachelors' continue with physics graduate study.[5]
- Graduate enrollments in physics have increased slowly and steadily in the 1980s. However, the increases are solely due to increases in foreign students; the number of U.S. physics graduate students has been stable since 1980.[6]
- Solid state, elementary particle, and nuclear physics are the leading specialties, but optics, medical physics, and plasma physics are expanding. Increasing attention to industry and government-related studies in graduate education has bolstered interdisciplinary study, particularly with engineering.
- Many physics graduate students take terminal master's degrees. Among those who earn a Ph.D., almost half accept postdoctoral appointments. This reflects the poor job market for physicists over the past decade.

Foreign Nationals, Women, and Minorities

- The presence of foreign nationals in physics has increased rapidly since the mid-1970s. Twenty-seven percent of physics Ph.D.s were awarded to foreign students on temporary visas in 1985, an additional 3 percent to those on permanent visas. Over one-third of currently enrolled physics graduate students are foreign

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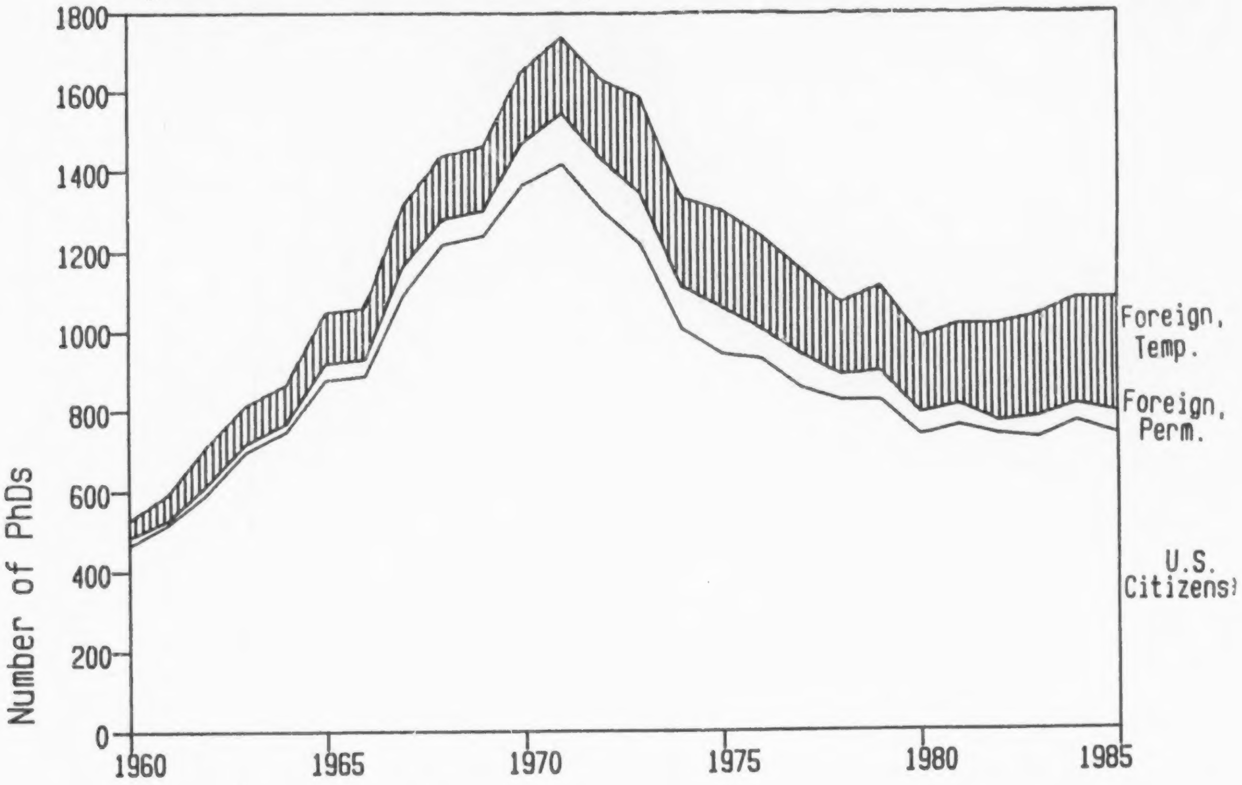
[5] National Research Council, Physics Survey Committee, Physics Through the 1990s: An Overview (Washington, DC: National Academy Press, 1986), p. 110.

[6] National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983, NSF 85-300 (Washington, DC: 1985), pp. 104, 130-31, tables C-6, C-27, C-28, and unpublished NSF data on 1984 and 1985 enrollments.

Physics* PhD Awards by Visa Status, 1960-1985



*includes Astronomy **includes unknown citizenship Source: NRC nationals.[7] Among the sciences, physics has a high proportion of foreign nationals among employed Ph.D.s — nearly 8 percent.[8]

- Women are still scarce in physics. Their participation is the lowest of all sciences, at all degree levels. Between 1980 and 1985, women received just over 7 percent of the physics Ph.D.s, awarded.
- Minorities hover around 1 to 2 percent of employed Ph.D. physicists. Blacks and Hispanics are making little progress, while Asians are doing relatively well and improving. In the past ten years, Asian Americans have received seven times as many physics Ph.D.s as blacks and five times as many Hispanics. Although U.S. citizens, many of these Asian Americans are foreign-born.

Astronomy

- There is a continuing oversupply of astronomers; research jobs are severely limited. Over half of Ph.D. astronomers work in Ph.D.-producing universities, many as non-faculty researchers and postdoctorates; many of the rest work in government.

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[7] Ibid.

[8] National Science Foundation, Characteristics of Doctoral Scientists and Engineers in the United States: 1983, op. cit., p. 12, Table B-3.

CHEMISTRY

Employment

- The chemistry work force is large and heavily industrial. Chemistry is second only to the biological sciences in number of researchers.
- There are between 129,000 and 195,000 chemists employed in the United States most in science and engineering (S/E) positions. Over two-thirds of S/E chemists are employed in industry, about 20 percent in academia and over 10 percent in Federal, State and local government.[9]
- Over one-third of the S/E employed chemists are engaged in research and development (R&D). Another 25 percent are in management positions and 14 percent in teaching.[10]
- The demand for chemists is driven in great part by industry. Industry conducts a significant amount of chemistry research; about 25 percent of the basic research community works in industry. The chemical industry employs the highest proportion of Ph.D.s of any industry.
- Of employed chemists, one-quarter hold the Ph.D. and the master's respectively. The terminal degree of the rest is the bachelor's. There is no shortage of chemists. Chemistry is a flexible discipline; when one segment of the industry is in a downturn, chemists find related jobs. Chemists are relatively mobile; in 1983, one in three Ph.D. chemists were employed in other fields, compared to one in five computer science and two in five physics/astronomy Ph.D.s.[11]

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[9] In 1985, the Bureau of Labor Statistics reported 129,000 chemists, including 18,000 teachers. The Census Bureau estimated 110,620 chemists in 1980. The National Science Foundation's preliminary 1986 estimate is 195,200. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Table B-1, unpublished data.

[10] Ibid, Table B-13.

[11] National Research Council, Office of Scientific and Engineering Personnel, Science, Engineering and Humanities Doctorates in the United States: 1983 Profile (Washington, DC: National Academy Press, 1985), p. 18,

- Technicians are particularly important to chemistry R&D and production, but little is known about them. Some have a bachelor's in chemistry and many enter the market with 2-year associate degrees. The chemical industry employs around 40,000 chemical technicians; perhaps another 20,000 are employed in other manufacturing industries.[12]

Education

- Increasingly, a Ph.D. is the accepted qualification not only for academic employment in chemistry, but for industrial employment as well. About 1,800 Ph.D.s are awarded annually in chemistry.
- About 11,000 students get a bachelor's degree in chemistry each year. Fewer than 2,000 of these students go on for a Ph.D.; another 1000 get a master's. The average time to Ph.D. for 1984 chemistry Ph.D.s was slightly over 6 years since bachelor's, the fastest of all fields.
- One or more years of postdoctoral research is accepted preparation for an academic research career. Almost one-half of new Ph.D.s go on to a postdoctoral appointment.[13]

Foreign Nationals

- The number of foreign graduate students in chemistry is rising slowly, although it is not as high as in physics and engineering. In 1985, nearly one in five of the Ph.D.s awarded went to foreign nationals on temporary visas; an additional 5 percent went to foreign nationals on permanent visas.

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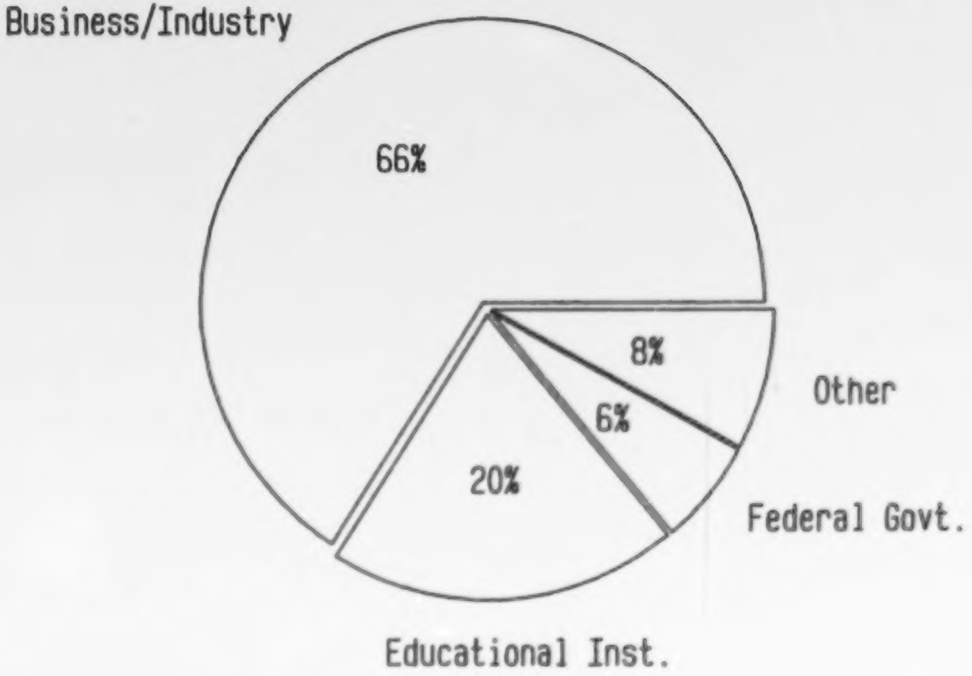
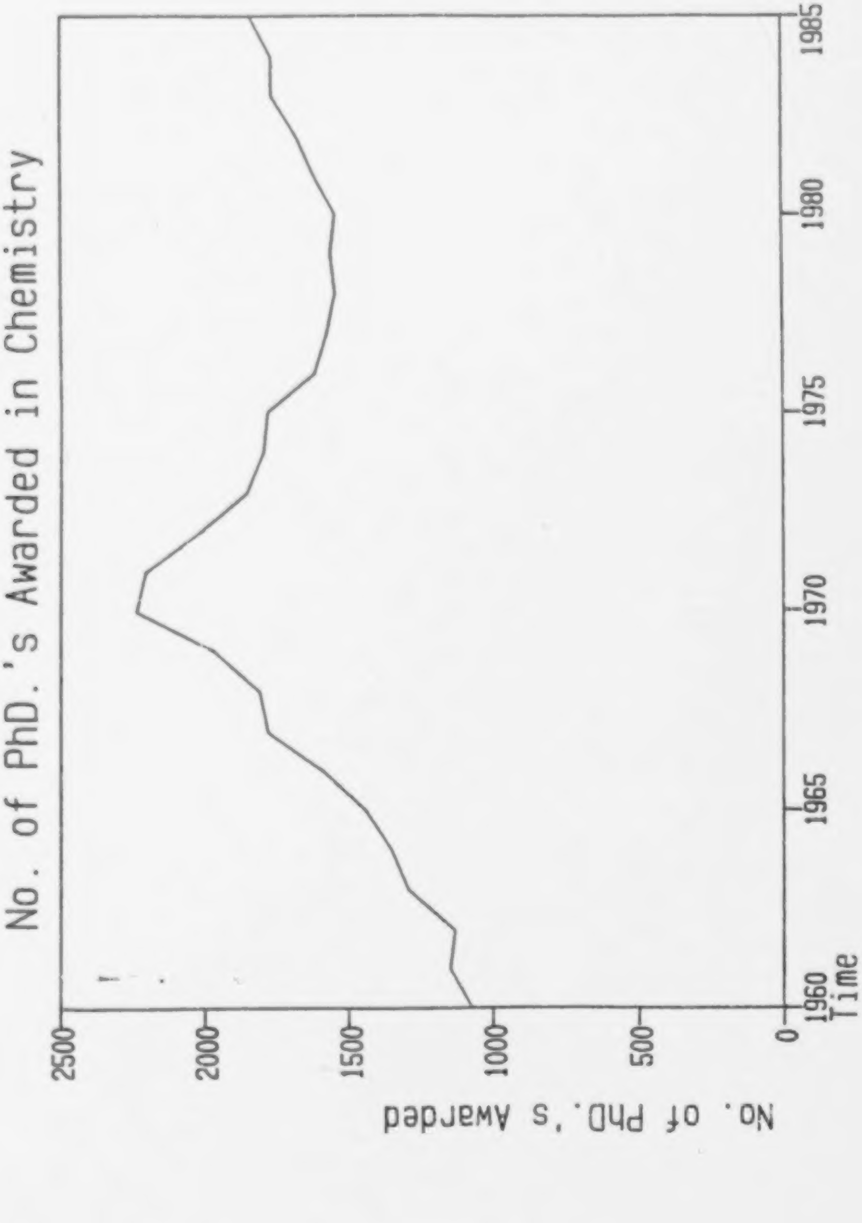
12. National Science Foundation, Scientists, Engineers, and Technicians in Manufacturing Industries: 1983, NSF 85-328 (Washington, DC: 1985), p. 23, Table D-2.
13. National Research Council, Office of Scientific and Engineering Personnel, Doctorate Recipients from United States Universities: Summary Report 1984 (Washington, DC: National Academy Press, 1986), p. 34, Table 2.

Where Chemists Work, 1986



SOURCE: NATIONAL SCIENCE FOUNDATION


No. of PhD.'s Awarded in Chemistry
No. of PhD.'s Awarded
0
500
1000
1500
2000
2500
1960
1965
1970
1975
1980
1985
Time

- More foreign students are staying in the United States after receiving their doctorate. Three in five on temporary visas enter postdoctoral research, with only 5 percent going directly into industry.

Women and Minorities

- Women have made slow but steady progress in chemistry at all degree levels. The proportion of chemistry Ph.D.s earned by women has doubled in 10 years, from 10 percent in 1975 to nearly 20 percent in 1985.
- Women are 13 percent of employed chemists (up from 6 percent a decade ago), but over one-quarter of unemployed chemists seeking work. Women in academia are more likely to be in junior positions, untenured, and more than twice as likely to be working part time.
- Blacks and Hispanics have made no gains in chemistry in the past 10 years. Blacks receive less than 2 percent of chemistry Ph.D.s, and barely more than 2 percent of bachelor's degrees. In comparison, Asian-Americans earned 6 percent of the chemistry Ph.D.s in 1985, up from 1 percent in 1975.

EARTH AND ENVIRONMENTAL SCIENCES

Overview

- The earth and environmental sciences encompass marine and atmospheric sciences in addition to the traditional core of geological sciences and geophysics. The field is small and interdisciplinary.
- Demand is especially unpredictable in the earth sciences. Expansion through the mid-1970s was halted by the OPEC-triggered recession. In 1981, 60 percent of companies reported a shortage of petroleum engineers; 2 years later, the shortage was down to 20 percent.[14] There is currently no shortage.
- There is a surplus of bachelor's and master's earth scientists who began their education just before the current downturn in the petroleum and mining industries curtailed exploration and surveying. Government employment is more stable, but modest. The academic market is poor.

Employment

- There are between 60,000 and 112,500 earth and environmental scientists employed in the United States.[15] With 90 percent in science and engineering (S/E) positions. Of these, earth scientists outnumber atmospheric scientists and oceanographers combined 4 to 1.[16]

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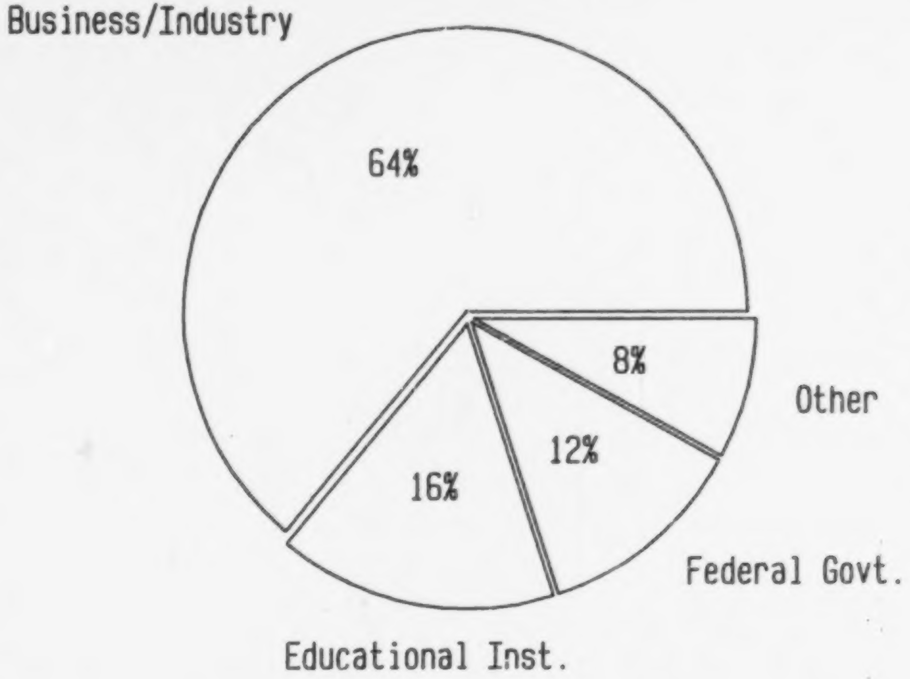
14. Based on 1981-85 tabulations of the Rapid Industry Limited Response Survey Panel on Science/Engineering Personnel Resources, reported in Joel Barriers, "Shortages Increase for Engineering Personnel in Industry," Highlights, NSF 85-309 (Washington, DC: March 29, 1985).

15. In 1985, the Bureau of Labor Statistics reported 63,000, which included 58,000 geoscientists plus 5,000 earth, environmental and marine science teachers. The National Science Foundation's preliminary 1986 estimate is 112,500 employed in the U.S. work force. This includes 94,300 earth scientists, 14,400 atmospheric scientists, and 3,700 oceanographers. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Table B-1, unpublished data.

Where Earth Scientists Work, 1986



SOURCE: NATIONAL SCIENCE FOUNDATION

- Of the 86,000 earth scientists estimated to be employed in S/E positions in 1986, two-thirds are employed in industry, while the rest distribute almost equally in academia and the Federal Government.[17]
- One-third of the S/E employed earth scientists are engaged in research and development, one quarter are in production activities, less than one-fifth in management. Less than 10 percent are estimated to be primarily engaged in teaching.[18]
- Earth and environmental science Ph.D.s exhibit the lowest mobility of all science and engineering doctorate holders. In 1983, only one in five was employed outside his/her specialty.[19] In 1985, however, less than 1 percent of Ph.D. earth and environmental scientists were unemployed and seeking jobs.[20]

Education

- The master's, and to a lesser extent the bachelor's, are entry level degrees. Earth scientists are much less likely than physicists or chemists to have a Ph.D.
- Bachelor's awards in earth science, now about 7,000 per year, have increased steadily since the mid-1960s. About 2,000 master's degrees are conferred each year.[21]
- Earth sciences Ph.D.s have fluctuated around 600-650 per year for the past 10 years, with geological sciences slightly more than half the total.[22] The production

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16. Ibid., Table B-13.
17. Ibid.
18. Ibid.
19. National Research Council, Office of Scientific and Engineering Personnel, Science, Engineering and Humanities Doctorates in the United States: 1983 Profile (Washington, DC: National Academy Press, 1985), p. 18, Table 2-2.
20. National Research Council, Office of Scientific and Engineering Personnel, unpublished data from the seventh (1985) biennial survey of U.S. doctorate recipients.
21. Earth sciences degree data based on surveys conducted by the American Geological Institute, cited in Manpower Comments, vol. 23, No. 5, June 1986, p. 18.
22. National Science Foundation, Science and Engineering Doctorates: 1960-82, NSF 83-328 (Washington, DC: no date), p. 17, Table 1. Data for 1983-85 from National Research Council, Office of Scientific and Engineering Personnel, Doctorate Recipients from United States Universities (Washington, DC: National Academy Press).

of Ph.D.s rose steadily through the 1960s and plateaued in the early 1970s. Recent graduate enrollments have declined, probably in response to the poor job market.

Women, Minorities, and Foreign Nationals

- The number of female earth scientists has increased rapidly since 1970, but there are still relatively few among professional ranks. Women earn about one-quarter of bachelor's and master's earth science degrees, and almost one-fifth the Ph.D.s awarded. However, they are still only 6 percent of employed Ph.D.s and at best 10 percent of all employed earth scientists.[23]
- Minorities have not made inroads into the earth sciences. Blacks are less than 1 percent of employed earth scientists, Hispanics and Asians about 2 percent each.[24] Earth sciences attract fewer Asians than do other sciences. Among recent earth science Ph.D.s, 0.5 percent are black, 1 percent Hispanic, and 3-5 percent Asian-American.[25]
- The earth sciences attract fewer foreign students than other physical sciences; one in five 1985 Ph.D.s were foreign students on temporary visas.[26] The number proportion of foreign nationals in earth and environmental science graduate programs increased slightly between 1980 and 1985. In 1985, foreign nationals represented about 15 percent of full-time earth and environmental graduate students.[27]

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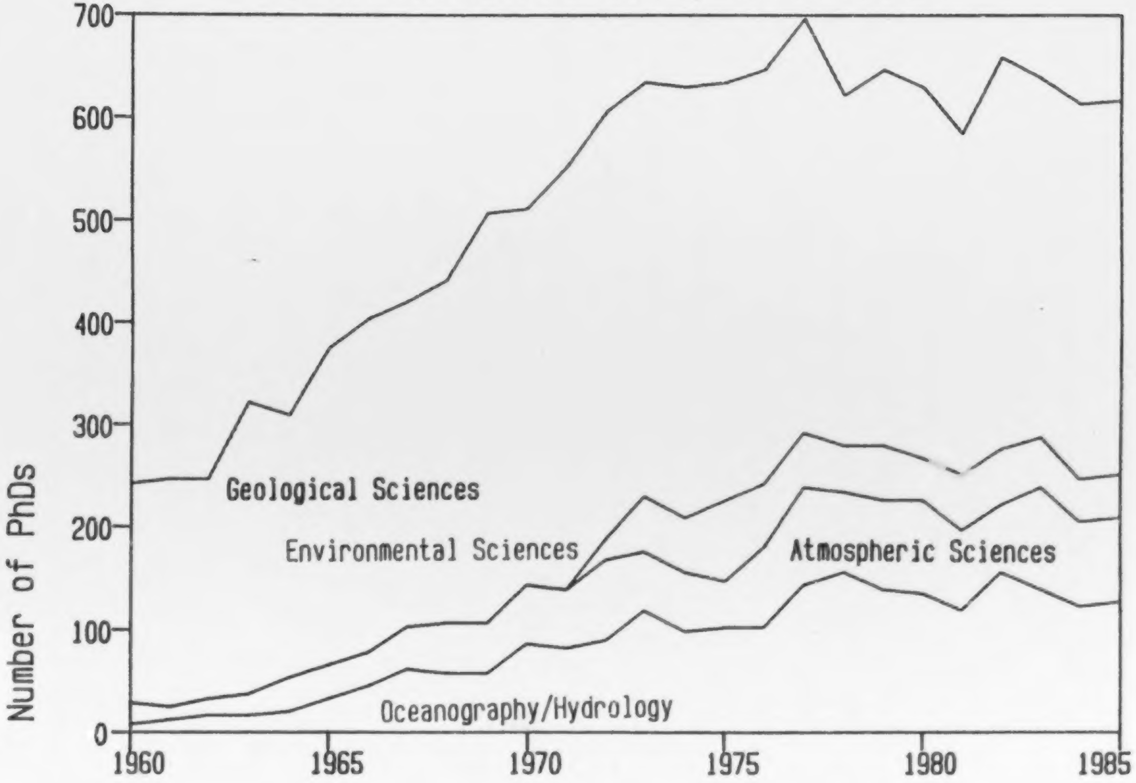
23. National Science Foundation, U.S. Scientists and Engineers: 1984, op. cit. p. 100, Table B-9; and National Science Foundation, Science and Engineering Personnel: A National Overview, NSF 85-302 (Washington, DC: 1985), p. 116, Table B-12b.
24. National Science Foundation, U.S. Scientists and Engineers: 1984, op. cit., p. 53, Table B-5.
25. National Research Council, Office of Scientific and Engineering Personnel, op. cit.
26. Ibid.; data for 1985 are unpublished.
27. National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support: Fall 1983, NSF 85-300 (Washington, DC: 1985), p. 102, Table C-5, and "Selected Data on Graduate Science/Engineering Students and Postdoctorates by Citizenship," Science Resources Studies, National Science Foundation, unpublished data, October 1986, Tables B-13 and B14.

Earth Sciences PhDs, 1960-1985



Source: NRC

MATHEMATICAL AND COMPUTER SCIENCES

The mathematical and computer sciences are a union of old and new that is altering both fields. Computer science is a young and interdisciplinary field with theoretical roots in mathematics and close ties to engineering. Computer science emerged from mathematical computer theory during the 1960s. Research in the two fields is intimately connected. For this reason, they are profiled in a section of their own.

Mathematics is closely tied to advances in computer theory and applications. In turn, high-speed computer graphics and numerical analysis have spurred new advances and directions in mathematical research. Because of close ties in research, theory, and financial support, it is difficult to separate data and analysis of degrees, the work force, and financial support in the two fields. For example, the 15-year decline in math degrees has been accompanied by an increase in computer science degrees.

In addition, much of industry demand for computer scientists has been interchangeable with demand for electrical engineers. Data and trends in computer science are related to computer engineering, the fastest growing engineering specialty.

In 1984, the David Report argued vigorously for increased Federal support of mathematical research as a resource to other fields.[28] The recent Griffiths Report on the mathematical sciences reinforces this view:

> Mathematics is the underpinning of revolutionary changes taking place in all scientific and engineering fields as a result of the advent of powerful computers. The development of scientific computing has not only highlighted a host of critical new mathematical problems, it has introduced new tools for mathematicians.[29]

For these reasons alone, education and employment in the mathematical and computer sciences are seen as especially vital to the future health of U.S. science and technology.

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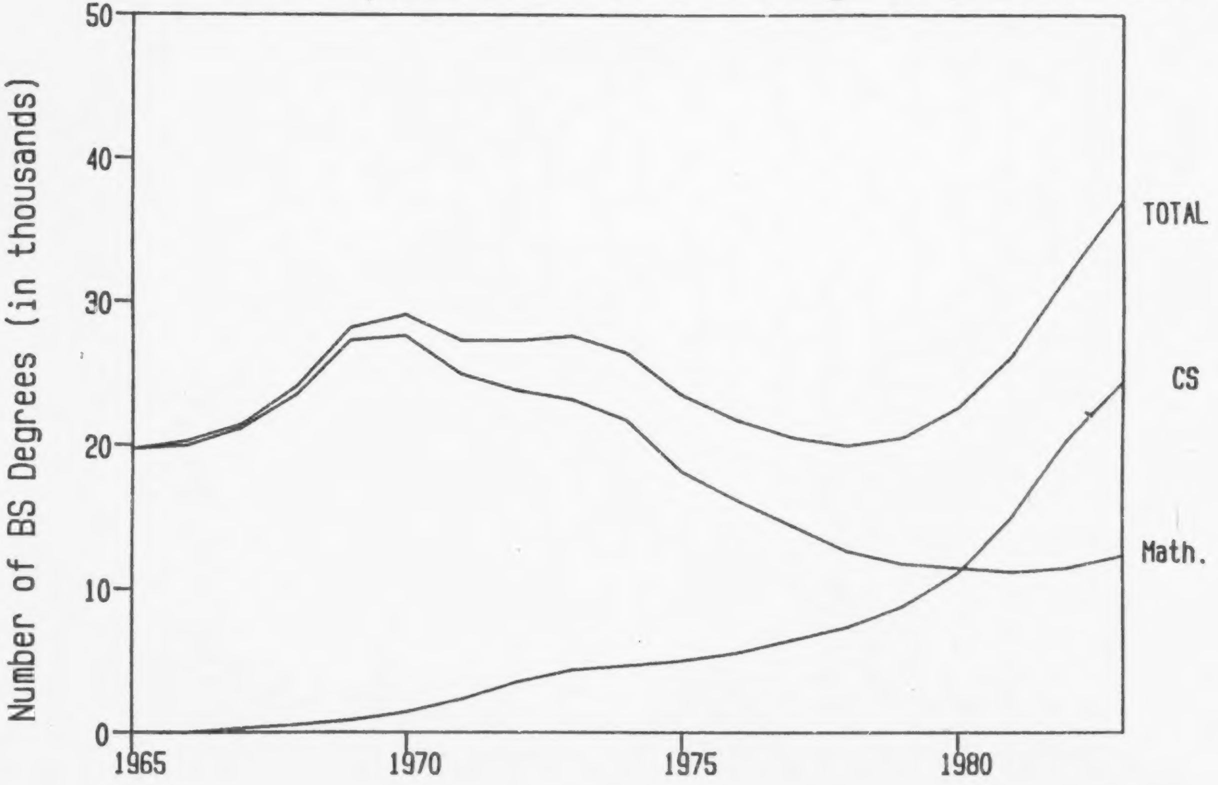
[28] National Research Council, Renewing U.S. Mathematics: Critical Resource for the Future (Washington, DC: National Academy Press, 1984).

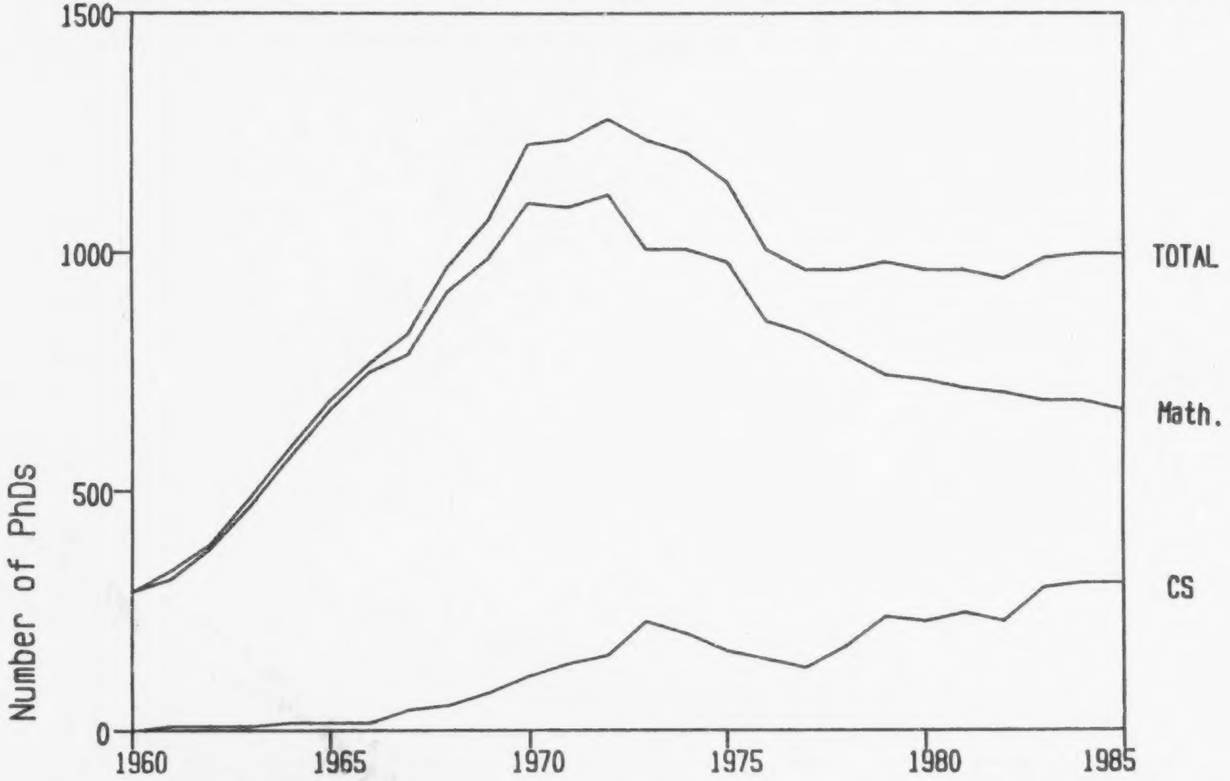
[29] National Research Council, Mathematical Sciences: A Unifying and Dynamic Resource (Washington, DC: National Academy Press, 1986), p. 5.



Math. and Computer Sciences BS Degrees, 1965-1984

Source: NCS

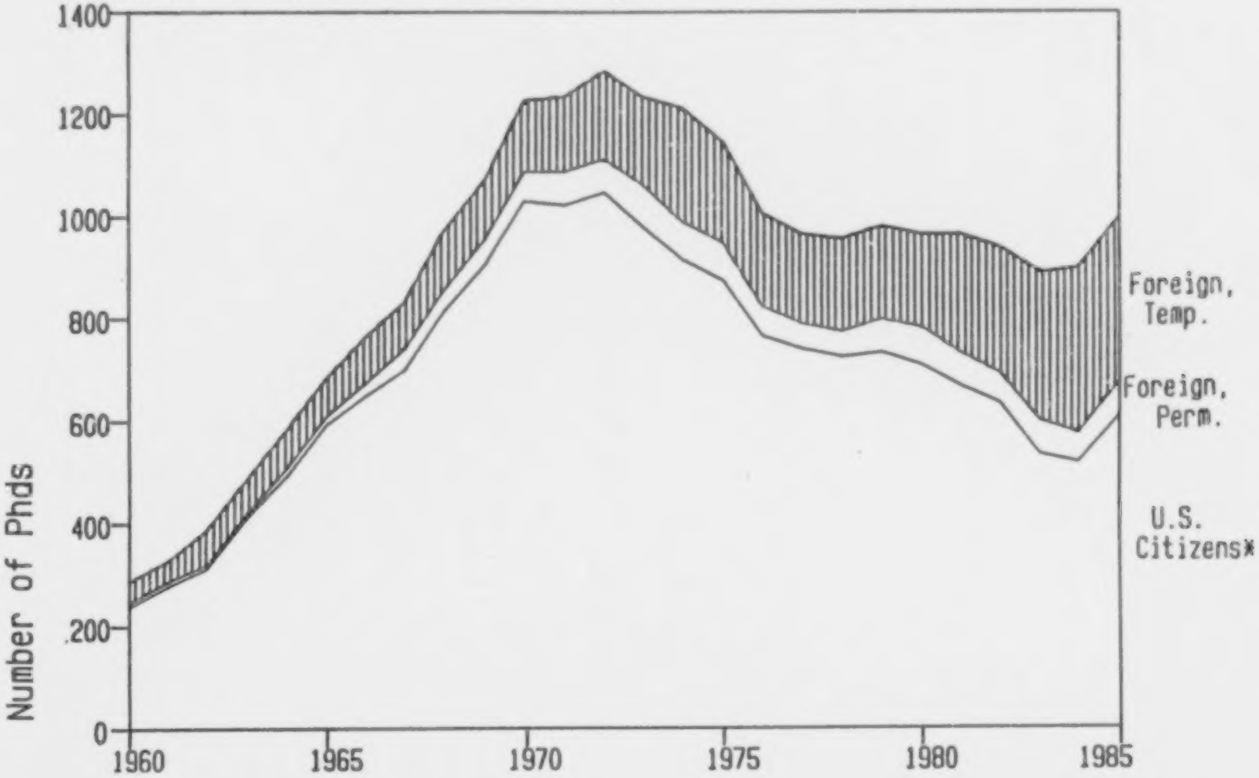
Mathematics and Computer Sciences PhDs*, 1960-1985



*PhDs in computing theory
included under computer sciences

Source: NRC

Math. & CS PhD Awards by Visa Status, 1960-1985



*includes unknown citizenship

Source: NRC

MATHEMATICAL SCIENCES

Employment/Demand

- In 1986, there are estimated to be 116,400 mathematicians and statisticians employed in the United States. Ninety percent are employed in science and engineering (S/E) positions, with one-third working in industry, one-half in academia, and most others in the Federal Government.[30]
- The basic research community in the mathematical sciences numbers between 4,000 and 7,000, representing over 90 percent of the mathematics college and university faculty.[31] Research in applied mathematics and statistics often extends to problems in other fields such as engineering, computer science, optics, and biology.
- Mathematicians are the most likely of all doctorate scientists to be academically employed. In 1986, one-half of all mathematicians are estimated to be working principally in teaching. Based on the 1985 NRC survey, three out of four Ph.D. mathematicians are employed in educational institutions.[32] Ph.D. statisticians, however, are less likely to work in academia. Mathematicians have the highest tenure rate of all scientists, 70 percent.

Education/Supply

- Ph.D. awards in mathematics peaked in 1970 (at 1,236), sharing in the across-the-board proliferation in science funding and enrollment during the 1960s.[33] These graduates created a substantial bulge in the supply of mathematicians; while Federal support fell (in real terms) during the 1970s, the number of mathematical researchers doubled.

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[30] National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Tables B-1 and B-13, unpublished data.

[31] National Research Council, Panel on Mathematical Sciences, Mathematical Sciences: A Unifying and Dynamic Resource (Washington, DC: National Academy Press, 1986), p. 34

[32] National Research Council, Office of Scientific and Engineering Personnel, unpublished data.

[33] National Science Foundation, Science and Engineering Degrees: 1950-80. A Source Book, NSF 82-307 (Washington, DC: 1982), p. 49, Table 29, and National

- Ph.D. awards dropped 41 percent between 1970 and 1980 and a further 7 percent from 1980 to 1985.[34] Surveys by the Mathematical Association of America indicate that the demand for undergraduate mathematics teaching exceeds the supply of fully qualified teachers. More undergraduates are being taught by part-time faculty.
- There are about 10,000 enrolled graduate students, but only about 700 Ph.D.s are awarded in mathematics each year. The average length of graduate study for those who do get degrees is nearly 7 years.
- In 1983, one in five math Ph.D.s planned postdoctoral study. A higher proportion of foreign students go on to a postdoctorate; in 1985 one-half of the mathematics postdoctorates were foreign nationals.[35]
- Mathematics bachelor's and master's degrees peaked in 1970 and 1969, respectively, dropped precipitously through the 1970s, and have rebounded slightly in the 1980s. Graduate enrollments have also risen slightly, though the rebound has not increased Ph.D. awards.
- It is important to look at mathematics and computer sciences degree data together, since the decline in mathematics degrees during the late 1970s was accompanied by an increase in computer science degrees. At the bachelor's level, a rapid rise in computer sciences during 1975 to 1985 masked a continuing drop in mathematics

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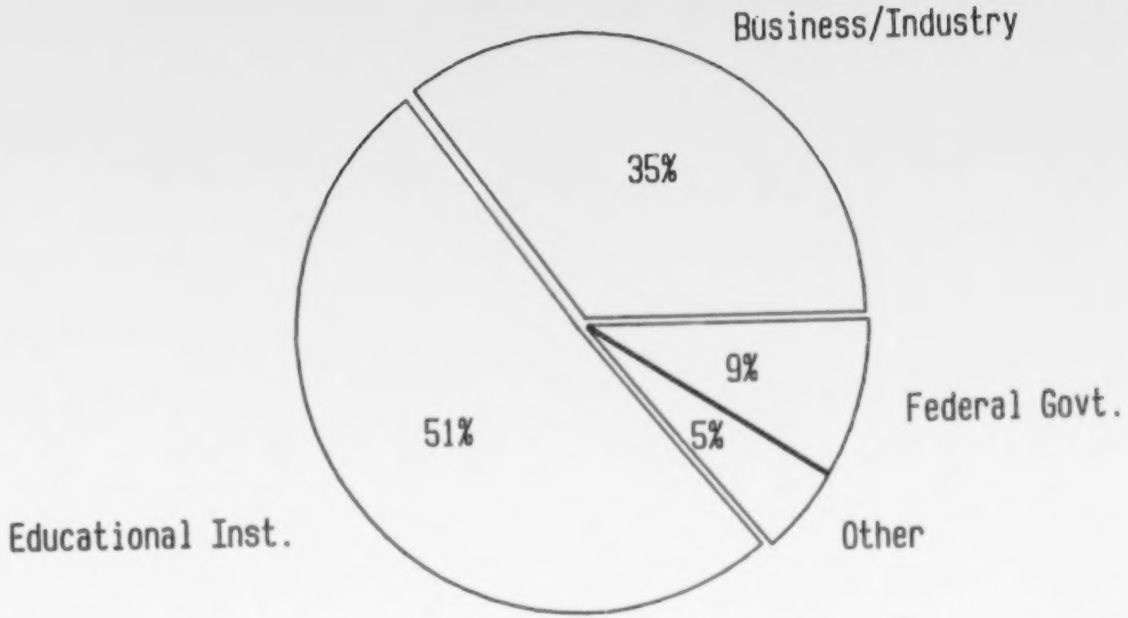
Research Council, unpublished data.

[34] Ibid.; data for 1981-84 from the National Research Council, Office of Scientific and Engineering Personnel, annual surveys of doctorate recipients from U.S. universities, 1985 unpublished data (does not include Ph.D.s in computer science).

[35] National Science Foundation, "Selected Data on Graduate Science/Engineering Students and Postdoctorates by Citizenship" Fall 1985," unpublished data, Science Resources Studies. Table A-24.

Where Math. Scientists Work, 1986



Source: National Science Foundation

degrees. By 1983, bachelor's degrees had started rising and the drop in mathematics Ph.D.s had slowed.

Foreign Nationals

- The proportion of mathematics Ph.D.s awarded to non-U.S. citizens is substantial and increasing. In 1985, one in three mathematics Ph.D.s were awarded to non-U.S. citizens on temporary visas, up from one in five in 1976. Between 1980 and 1984, the number of mathematics Ph.D.s awarded to non-U.S. citizens rose 30 percent, while the total number of mathematics Ph.D.s fell.[36]
- Half as many U.S. citizens received mathematical sciences Ph.D.s in 1985 as in 1973. Of foreign mathematics Ph.D. recipients with temporary visas, perhaps one-half stay in the United States for some time. For those who had firm post-graduation plans, 60 percent planned to stay in the United States for study or work in 1982, up from 40 percent in 1972.[37]
- Over 90 percent of new foreign Ph.D.s on permanent visas stay in the United States. In 1982, 5 percent of employed mathematicians were foreign nationals and more than 10 percent were naturalized citizens.[38]

Women and Minorities

- Women have long had a significant presence in mathematics, particularly at the bachelor's level. One in five employed mathematicians is a woman.[39] Although over 40 percent of bachelor's degrees are awarded to women. only 30 percent of employed baccalaureate mathematicians, and less than 10 percent of employed Ph.D. mathematicians are women.[40]

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[36] National Science Foundation, Science and Engineering Doctorates: 1960-82, NSF 83-328 (Washington, DC: 1983), pp. 44-45, Table 2. Data for the 1981-85 period from, National Research Council, Office of Scientific and Engineering Personnel, op. cit.

[37] National Science Foundation, Foreign Citizens in U.S. Science and Engineering, op. cit., p. 63, Chart 3.10.

[38] Oak Ridge Associated Universities, Labor and Policy Studies Program, Foreign National Scientists and Engineers in the U.S. Labor Force, 1972-1982 (Oak Ridge, TN: June 1965), p. 42, Table A-17.

[39] National Science Foundation, U.S. Scientists and Engineers: 1984, op. cit., p. 57, Table B-6.

- The 1984 unemployment rate for women in mathematics was 2.8 percent; for men it was 2 percent. The 1984 underemployment rate was 6.1 percent for women and 2 percent for men.
- Women receive about one-third of master's degrees in mathematics. This share has been fairly steady since the beginning of the 1970s, and was not much lower during the 1960s.
- Women receive about 15 percent of the Ph.D.s in mathematics and only recently have achieved even this level of participation. (The picture is similar in statistics.) The advance of women in the mathematical sciences seems to have plateaued during the 1980s.
- Seven blacks received mathematics Ph.D.s in 1985 — about 1 percent of the mathematics Ph.D.s granted that year.[41] Blacks receive about 5 percent of bachelors degrees in mathematics. Minority students, and to a lesser extent women, are handicapped by their lower exposure to mathematics in high school.
- Blacks are less than 5 percent of all employed mathematicians at all degree levels. This proportion is the same for Asians, but even smaller for Hispanics. In addition, blacks and Asians are more likely to be in teaching and less likely to be in research and development.

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[40] National Science Foundation, Science and Engineering Degrees: 1950-80, op. cit., p. 49, Table 29; and National Science Foundation, Science and Engineering Personnel: A National Overview, op. cit., p. 115, Table B-12b.

[41] National Research Council, Office of Scientific and Engineering Personnel, op. cit.

COMPUTER SCIENCE

Education/Supply

- Computer science is the fastest growing science. Between 1977 and 1985, the number of computer science graduate students rose more than 15 percent per year, from 9,000 to nearly 30,000.[42]
- In 1985, about 315 computer science Ph.D.s were awarded. Over the past 3 years, computer science Ph.D. awards have increased 5-15 percent per year, and the rate is accelerating.[43]
- Graduate students in computer science come from a wide variety of undergraduate degrees and the majority of practicing computer scientists do not have a formal degree in the area. Less than 20 percent of recent computer science Ph.D.s have a bachelor's in computer science.
- Significant in-mobility of Ph.D.s into computer science is from mathematics and physics. With a declining supply of mathematics Ph.D.s and a growing pool of computer science Ph.D.s, this influx should dwindle through the 1980s as the field matures.[44]
- More than half of computer science graduate students in 1985 were part time, by far the highest of all sciences and engineering. Computer science also has the smallest proportion of postdoctorates of any science or engineering field.

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42. National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983, NSF 85-300 (Washington, DC: 1985), p. 62, Table B-1; and unpublished data.

43. National Research Council, Office of Scientific and Engineering Personnel, annual survey of doctorate recipients in U.S. universities, 1985 unpublished data.

44. The Computer Science Board, Committee on Research Funding in Computer Science, Imbalance Between Growth and Funding in Academic Computer Science: Two Trends Colliding (April 9, 1986), pp. 8-9.

- Over 6,000 master's degrees in computer science were granted in 1984, more than doubling since 1978. But the most explosive growth in computer science has been at the bachelor's level. There were 32,000 bachelor's degrees awarded in 1984, compared to less than 5,000 in 1975, an annual growth rate of 20 percent. And this pace has accelerated since 1980 to 30 percent per year.[45] Many universities are limiting undergraduate computer science enrollments while expanding their faculty to meet continuing demand.[46] This trend, however, will probably not continue. Only half the number of freshmen in 1985 as in 1983 indicated plans for a computer science major.

Employment/Demand

- Just under half of recent computer science Ph.D.s work in universities and colleges, and just under half in industry research and development. Demand for computer scientists is high, particularly at the Ph.D. level where it is three or four times current production.[47]
- Ph.D. computer scientists earn the highest salaries among scientists at the same experience level. Academic salaries are also well above the average and approach those of engineering and business faculty.
- Academic demand is still high and will continue to increase, though it has eased significantly from the near-crisis of the 1970s when potential faculty and graduate students flocked to lucrative jobs in industry.
- Federal funding and industry financial and equipment support have improved academic departments. The number of graduate departments of computer science increased from 91 in 1976 to 146 in 1983.[48]

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45. National Center for Statistics (1984, Table 112, unpublished data).
46. The Computer Science Board, Committee on Research Funding in Computer Science, Imbalance between Growth and Funding in Academic Computer Science: Two Trends Colliding (April 9, 1986), p. 6.
47. Ibid., p. 3.

- Departments are still understaffed, and shortages for computer science faculty in 4-year colleges are particularly high. One analyst estimates that only half of current computer science faculty have a Ph.D., and only half of these have their Ph.D. in computer science.[49]
- Competition among universities, colleges, high-paying industry, and large research institutes for a limited pool of Ph.D.s is brisk. Fifteen percent of academic positions for computer science went unfilled in 1981-83.[50]
- Computer scientists are the youngest and least tenured of academic scientists. Almost 40 percent of faculty in graduate departments are assistant professors, with 35 percent full professors.[51]
- Over three-quarters of baccalaureate computer scientists go directly into industry, where salary offers are the highest among the sciences and almost as high as engineering.

Foreign Nationals

- Foreign students have joined the technological gold rush to computer science. Foreign students on temporary visas received one-third the computer science Ph.D.s awarded in 1985, up from 11 percent in 1977. This pace is similar to that in engineering.[52]

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48. Ibid., p. 25, Table 1a.
49. John W. Hamblen, Computer Manpower — Supply and Demand by States, 1984 (Tallahassee, FL: Quad Data Corp, 1984), cited in The Computer Science Board, op. cit., p. 10.
50. Scientific Manpower Commission, The Technological Marketplace: Supply and Demand for Scientists and Engineers, 3rd ed. (Washington, DC: May 1985), p. 38, Table 29.
51. The Computer Science Board, The 1984-85 Taulbee Survey, prepared by David Gries (Ithaca, NY: Department of Computer Science, Cornell University, June 1986), p. 6.
52. Ibid. The Taulbee Survey reports 122 foreign nationals out of a total of 326, or 37 percent, in 1985. The National Research Council, Office of Scientific and Engineering Personnel, op. cit., reports 89 foreign nationals

- Forty percent of full-time graduate students in Ph.D. schools are foreign. Foreign students receive about 5 percent of bachelor's and 20 percent of master's degrees in computer science.
- Most foreign computer scientists — at both the bachelor's and Ph.D. levels — remain to work in the United States, more than in any other field.[53] Foreign computer scientists are important as new hires in the electronics and computer industries as well as academe. In Silicon Valley companies they may be as high as one-third of the work force.[54]
- Foreign computer scientists comprise over one-third of university faculty, a proportion unmatched across the sciences or engineering.

Women and Minorities

- Computer science has been an accepting field of graduate study and employment for women. Nine percent of employed computer science Ph.D.s are women, the highest proportion outside the social and biological sciences. Women earned 10 percent of the Ph.D.s in 1985 and over one-third the bachelor's degrees in 1984.[55] One-quarter of full-time graduate students are women, as are those the National Science Foundation (NSF) classifies as "computer specialists."
- Minorities, with the exception of Asians, have not shared in the expansion of the field. Blacks have made no gains in the past 5 years; they currently receive 5-6 percent of Bachelor's degrees and less than 1 percent of Ph.D.s. Hispanics receive about 3 percent of bachelor's degrees and 1-2 percent of Ph.D.s.

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out of 311, or 29 percent.

[53] U.S. General Accounting Office, Plans of Foreign Ph.D. Candidates: Postgraduate Plans of U.S. Trained Foreign Students in Science/Engineering, GAO/RCED-86-102FS (Washington, DC: February 1986), p. 3.

[54] National Science Foundation, Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook (Washington, DC: 1985), p. 75, Charts 5.1 and 5.2.

[55] National Research Council, Office of Scientific and Engineering Personnel, op. cit., reports 33 of 311 Ph.D.s, or 10.6 percent, and the Computer Science Board, op. cit., reports 32 women out of 326 Ph.D.s, or 9.8 percent; bachelor's data from National Center for Statistics.

- Asians have doubled their participation over the past 5 years to over 5 percent of bachelor's and Ph.D. computer science degrees.
- Among NSF "computer specialists," 6 percent are Asian, 3 percent black, 2 percent Hispanic, and 0.4 percent American Indian. Under NSF/Bureau of Labor Statistics definitions, the single largest area of employment of minority scientists and engineers is computers.

LIFE SCIENCES

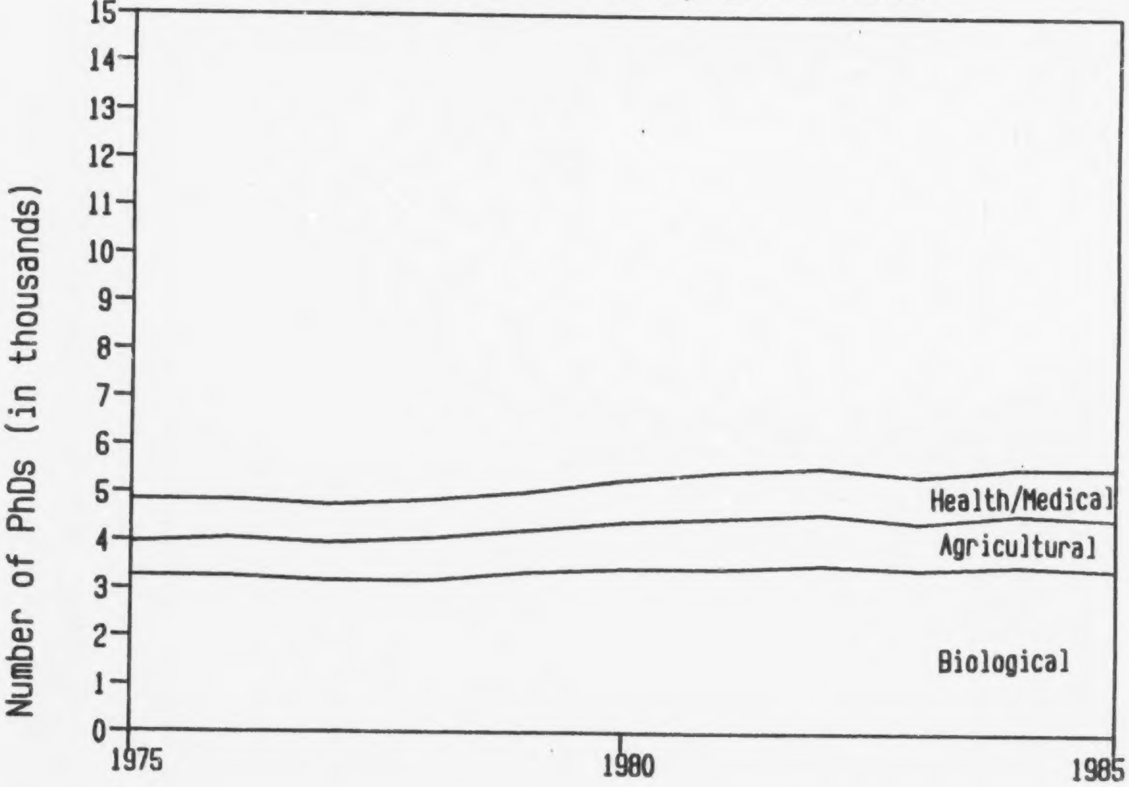
The life sciences represent a large number of fields that span the biological sciences, the health/medical sciences, and the agricultural sciences. Life sciences specialties are classified differently by data source. Their assignment to the biological or the health sciences sometimes depends on the academic department, school, or college which offers the program leading to the Ph.D., making comparisons difficult.

The biological sciences are comprised of a core set of disciplines devoted to the understanding of human and animal life. As the application of new and sophisticated instrumentation and the pace of biological discovery have accelerated, the boundaries between fields continue to blur. Basic biological fields represent the largest and most vibrant segment of the life sciences. In 1985, the biological sciences accounted for two-thirds of all life sciences Ph.D.s. Biochemistry is the largest disciplinary specialty; biochemistry plus microbiology, molecular biology, and physiology represented 41 percent of all life sciences Ph.D.s in 1985.

The health/medical sciences are a diverse set of health-related research specialties not directly involved in clinical care. These include environmental and public health, epidemiology, pathology, pharmacology, and nursing. Pharmacy/pharmacology represented one-third percent of all health/medical sciences doctorates awarded in 1985. These plus nursing and public health accounted for roughly three of every five health/medical sciences Ph.D.s conferred in 1985.

The agricultural sciences also consist of an array of fields and specialties. These include agronomy, animal science, plant science, soil science, food science and technology, range science, horticulture, fish and wildlife science, and forestry. The agricultural sciences represented one-fifth of the life sciences Ph.D.s awarded in 1985. Four broad specialties — agronomy, animal science, plant science, and food science — accounted for almost two-thirds of the 1985 agricultural sciences doctorates. This

Life Sciences PhDs, 1975-1985



Source: NRC

category does not include agricultural economics. The National Science Foundation science and engineering work force data count this field as a social science. About 160 Ph.D.s in agricultural economics are awarded each year (which the National Research Council classifies under the agricultural sciences).

The Nation's colleges and universities continue to produce large numbers of agricultural sciences graduates. Despite the currently widespread depression of the U. S. food and agricultural economy, agricultural products continue to constitute a large portion of U.S. exports and about 20 percent of U.S. civilian jobs are in food and agricultural industries. Much of the growth and relative stability in the employment of agricultural scientists the extensive nation-wide network of U.S. Department of Agriculture research facilities and the State agricultural experiment stations associated with the land-grant universities.

BIOLOGICAL SCIENCES

Employment

- There are 90,000 to 275,000 biological scientists employed in the United States. Of these, over 80 percent are employed in science and engineering (S/E) positions.[56]
- Less than one-half of the biological sciences S/E work force is employed by educational institutions. Industry employs about one-quarter and the Federal Government 15 percent.[57]
- About 40 percent of biological scientists in the S/E work force are engaged primarily in research and development (R&D), with more than half of them conducting basic research. One-fifth are in various management and teaching positions respectively.[58]
- There are about 66,500 Ph.D.s in the biological sciences work force — about a quarter of the total; master's degrees holders represent another one-third of this work force.[59]
- More than one-half of biological sciences Ph.D.s are principally employed in R&D positions, with over 20 percent in teaching, and 10 percent in various management positions.[60]

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[56] The Bureau of Labor Statistics reports 90,000 in 1985 (unpublished data); the National Science Foundation estimates 272,000 in 1986. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Table B-1, unpublished data.

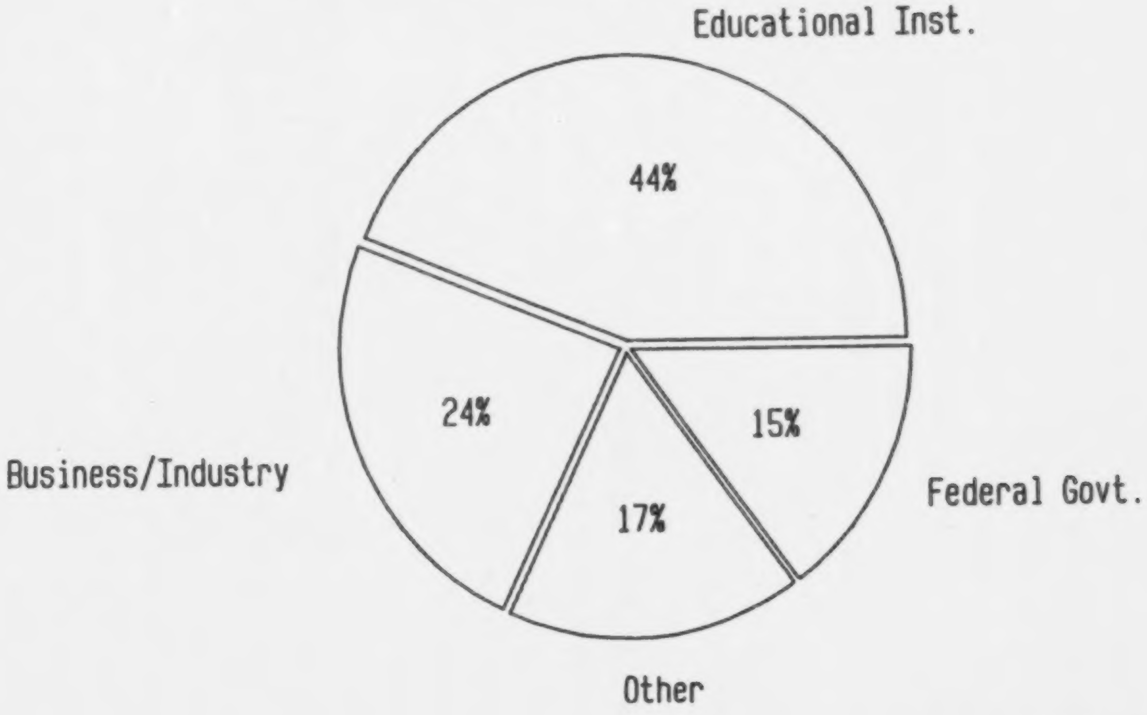
[57] National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Table B-13, unpublished data.

[58] Ibid.

[59] Ibid., Table B-11.

[60] National Science Foundation, Science and Engineering Personnel: A National Overview, NSF 85-302 (Washington, DC: 1985), pp. 116, 120, Table B-12b.

Where Bioscientists Work, 1986



Source: National Science Foundation

Education

- The number of bachelor's degrees awarded in the biological sciences has followed an erratic path. In 1950, slightly more than 24,000 bachelor's degrees were conferred. This number declined steadily through 1955 and began to increase to over 40,000 in 1970. The number of degrees peaked in 1976 at 59,000 and has declined each year since then. In 1984, 38,640 bachelor's degrees were awarded.[61]
- The number of Ph.D.s conferred in the biological sciences doubled between 1950 and 1960 to about 1,200 a year, reaching 2,100 in 1966. Between 1974 and 1985 the number of Ph.D.s has been between 3,100 and 3,500 each year.[62]
- The number of full-time graduate students in the biological sciences enrolled in doctorate-granting institutions declined slightly between 1977 and 1983, but has since turned upwards[63]

Women, Minorities, and Foreign Nationals

- Women's share of biological sciences bachelor's degrees increased from about 20 percent in 1950 to about 45 percent in 1984.[64] In 1985, women accounted for one in three Ph.D.s conferred in the biological sciences.[65]
- In 1986, women constitute one-fourth of the biological sciences work force and one-fifth of the doctorate-level contingent of this work force.[66]

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[61] National Science Foundation, Science and Engineering Degrees: 1950-80, NSF 82-307 (Washington, DC: 1982), p. 53, Table 33. Data for 1981-84 from the U.S. Department of Education, National Center for Statistics, unpublished.

[62] Ibid.; Ph.D. data for 1981-85 from National Research Council, Office of Scientific and Engineering Personnel, Doctorate Recipients From United States Universities (Washington, DC: National Academy Press, annually).

[63] National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983, NSF 85-300 (Washington, DC: 1985), p. 113, Table C-14, "Selected Data on Graduate Science/Engineering Students by Enrollments Status, Fall 1985," unpublished data, NSF Science Resources Studies, Tables A-1 and C-6.

[64] National Science Foundation, Science and Engineering Degrees: 1950-80, op. cit, and NCS, unpublished data.

[65] National Research Council, op. cit.

[66] National Science Foundation, Science Resources Studies Division,

- Blacks are severely underrepresented in the biological sciences. They represent only 2 to 3 percent of the biological sciences work force and 1.5 percent of the doctorate-level employees.[67]
- Over 15 percent of the 38,000 full-time graduate students in the biological sciences in 1985 were foreign citizens — up from about 10 percent in 1976.[68]
- In 1985, foreigners on temporary visas received 11 percent of the biological sciences Ph.D.s.[69]
- Of the biological sciences Ph.D.s conferred in 1985, Asians accounted for 4 percent, black and Hispanics each under 2 percent.[70]

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preliminary 1986 estimates, Tables B-1, B-11.

67. Ibid., Table B-12.

68. National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support: Fall 1983, op. cit., pp. 130-31, Tables C27 and C28, and "Selected Data on Graduate Science/Engineering Students and Postdoctorates by Citizenship, Fall 1985" unpublished data, National Science Foundation, Science Resources Studies, Table A-9.

69. National Research Council, op. cit.

70. Ibid.

HEALTH/MEDICAL SCIENCES

Employment

- There are an estimated 32,000 to 47,000 health/medical scientists employed in the United States. Of these, over 90 percent are employed in science and engineering (S/E) positions.[71]
- About 60 percent of the health/medical sciences S/E work force is employed by educational institutions. Industry and nonprofit institutions account for about 17 percent each and the Federal Government for 4 percent.[72]
- About 40 percent of the health/medical sciences S/E work force is engaged primarily in research and development (R&D), with 25 percent in some form of management and in teaching, respectively.[73]
- About two-thirds of health/medical scientists hold a doctorate. Less than 1 percent hold a master's degree.[74] Of the employed doctorate holders, one in three is engaged in R&D, one in five in teaching, and in some form of management.[75]

Education

- The number of Ph.D.s awarded annually in the health/medical sciences increased between 1975 and 1982 by 50 percent. In 1985, 1,082 Ph.D.s were conferred.[76]

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[71] The Bureau of Labor Statistics reports 47,000 in 1985 (unpublished data); National Science Foundation estimates 32,000 in 1986. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Table B-1, unpublished.

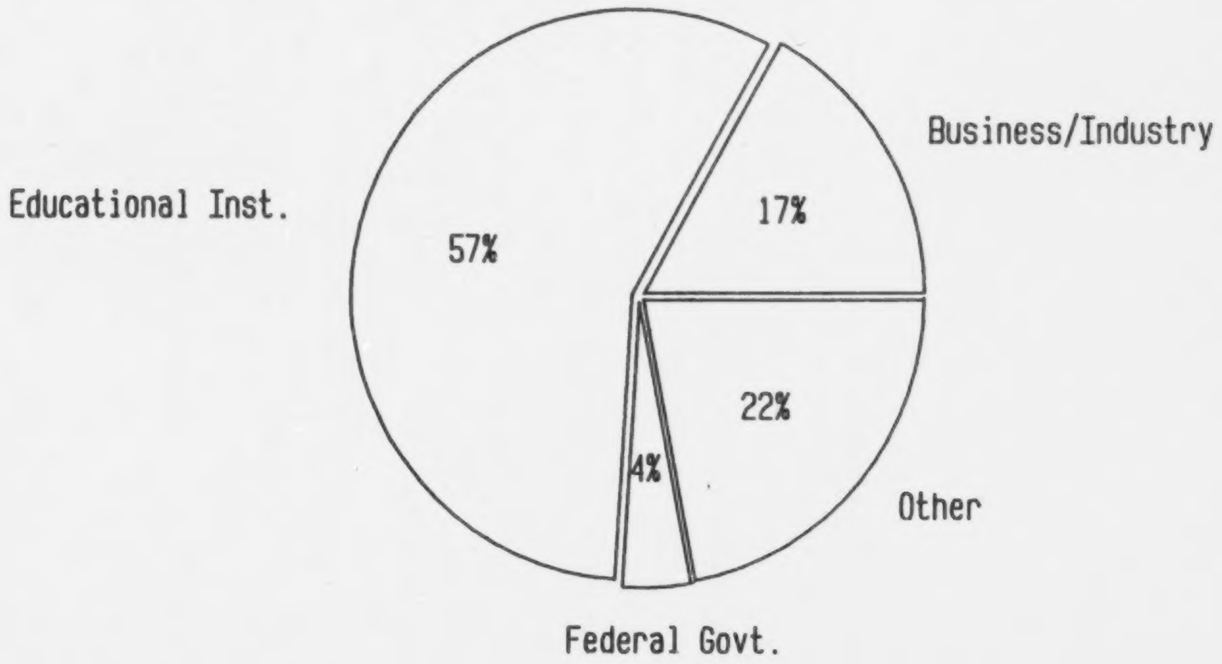
[72] Ibid., Table B-13.

[73] Ibid.

[74] Ibid., Table B-11.

[75] National Science Foundation, Science and Engineering Personnel: A National Overview, NSF 85-302 (Washington, DC: 1985), pp. 116, 120, and 124, Table B-12b.

[76] National Research Council, Office of Scientific and Engineering Personnel, Doctorate Recipients from United States Universities: Summary Report 1983 (Washington, DC: National Academy Press, 1983), p. 47, Appendix Table B. Data for 1985 are unpublished. Certain changes in the National Research Council doctorate fields were made to parallel National Science Foundation's occupational categories; degrees awarded in parasitology, pathology, and pharmacology were subtracted from the biological sciences and added to the health sciences.



Where Health Scientists Work, 1986

SOURCE: NATIONAL SCIENCE FOUNDATION

- The number of full-time graduate students in the health/medical sciences enrolled in doctorate-granting institutions increased between 1976 and 1980, declined slightly and has now plateaued.[77]

Women, Minorities, and Foreign Nationals

- Women earn a majority of the health/medical sciences doctorates. In 1985, women represented 60 percent of the Ph.D.s conferred in these fields.[78]
- Women's recent gains in earning doctorates have not yet shown up in the workplace. In 1984, women were over 20 percent of both the employed health/medical scientists and of the work force holding doctorates.[79]
- Blacks and Hispanics are severely underrepresented in these fields. In 1986, blacks and Hispanics each constituted slightly over 1 percent of the health/medical science work force and of the doctorate-holders in that work force.[80] In 1985, blacks received 3 percent of the health sciences Ph.D.s awarded.[81]
- The number of foreign full-time graduate students enrolled in doctoral programs has steadily increased since 1976, representing 11 percent of the health/medical sciences enrollment in 1985.[82]
- In 1985, foreign citizens on temporary visas received 13 percent of the health sciences Ph.D.s awarded.[83]

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77. National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983, NSF 85-300 (Washington, DC: 1985), p. 113, Table C-14; and unpublished data.
78. National Research Council, op. cit.
79. National Science Foundation, U.S. Scientists and Engineers: 1984, op. cit., pp. 37, 110, Tables B-1 and B-11.
80. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Table B-12.
81. National Research Council, op. cit.
82. "Selected Data on Graduate Science/Engineering Students and Postdoctorates by Citizenship Fall 1985" unpublished, Table A-15.
83. National Research Council, op. cit.

AGRICULTURAL SCIENCES

Education and Supply

- The number of students earning bachelor's degrees in agricultural and natural resources fields declined markedly between 1950 and 1961 from 15,000 to under 6,000 annually. After 1961 the fields showed steady growth, peaking at 22,000 in 1979 and declining slightly each year to about 19,000 in 1984. Master's degrees have followed a similar pattern since 1970 with over 4,000 conferred in 1984.[84]
- The number of Ph.D.s awarded nearly doubled between 1960 and 1970 to 800. Despite sharp fluctuations in the last 15 years, Ph.D. production has increased. Over 1,100 were awarded in 1985.
- No single discipline within the agricultural sciences accounts for more than 20 percent of the Ph.D.s. In 1985, the distribution was plant science and animal sciences, 18 percent each; food science, 12 percent; soil science and forestry, 9 percent each; and horticulture, and fish and wildlife, 7 percent each.

Employment

- There are an estimated 65,000 to 102,000 agricultural scientists employed in the United States. Of these, almost 80 percent are employed in science and engineering (S/E) positions.[85]
- Nearly one-half of the agricultural science S/E work force is employed in industry. About one-third are employed in academia and 10 percent in the Federal Government.[86]

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[84] National Science Foundation, Science and Engineering Degrees: 1950-80. A Source Book, NSF 82-307 (Washington, DC: 1982), p. 52, Table 32 and National Center for Statistics, unpublished data.

[85] The Bureau of Labor Statistics reports 65,000 in 1985 (unpublished); National Science Foundation estimates 101,900 in 1986. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Table B-1.

- Slightly less than one-third of the agricultural science S/E work force are primarily engaged in research and development (R&D) activities. About one-quarter are in various management positions and over one-fifth are involved in production/inspection. Less than 10 percent are engaged in teaching.[87]

Women, Minorities, and Foreign Nationals

- Women increased their proportion of the agricultural science S/E work force from 4 percent in 1976 to 19 percent in 1986. The majority of female agricultural scientists are employed in business and industry and 20 percent by educational institutions. About 30 percent are engaged in R&D activities.[88]
- Only 5 percent of agricultural science doctorates employed in 1986 are women, even though the proportion of Ph.D.s granted to women in agricultural science fields tripled from 5 to 15 percent in the 1975-85 decade.
- Minorities are likewise underrepresented. Blacks, Asians, and Hispanics each account for only 2 percent of the agricultural sciences work force in 1983. In 1985, Asians earned over 2 percent of the Ph.D.s awarded, blacks 1.4 percent, and Hispanics less than 1 percent (10 out of 1,100).[89]
- In contrast, foreign nationals receive about one-third of the Ph.D.s awarded, a proportion unchanged since 1975. The vast majority return to their country of origin.

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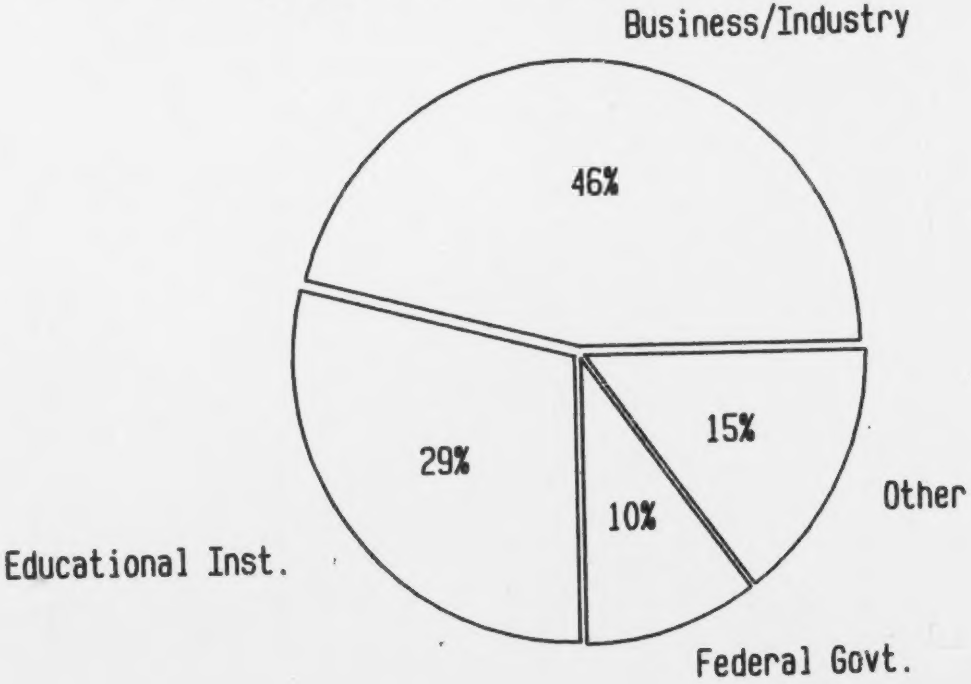
86. Ibid., Table B-13.
87. Ibid.
88. National Science Foundation, Science and Engineering Personnel: A National Overview, NSF 85-302 (Washington, DC 1985), Table B-2, p. 54 and National Science Foundation, Science Resources Studies Division, op. cit., Tables B-4 and B-6.
89. National Research Council, Office of Scientific and Engineering Personnel, 1985 unpublished data from the survey of doctorate recipients in United States universities.

Where Agricultural Scientists Work, 1986



SOURCE: NATIONAL SCIENCE FOUNDATION

SOCIAL AND BEHAVIORAL SCIENCES

The social and behavioral sciences encompass a variety of fields. They include anthropology, geography, political science, sociology, and two large but very different fields which are often reported on separately, economics and psychology. Some data sources treat psychology as a behavioral science, separate from other social sciences.

The bachelor's degree is insufficient for professional employment in the social and behavioral sciences. Thus, graduate enrollments and degrees are the best indicators for forecasting the supply of social scientists. Ph.D.s have been steady at around 6,000 a year since 1975, with psychology taking an increasing share while other social sciences have declined. Bachelor's degrees in social and behavioral sciences peaked in 1974 and have been dropping steadily ever since. Freshman interest has been fairly steady since the late 1970s, although it dipped in 1980-1983 at the same time that interest in engineering peaked. For all these fields combined, about 14 percent of bachelor's graduates earn a master's and 5 percent a Ph.D.[90]

It is difficult to estimate the number of social and behavioral scientists working in this broad field; the Bureau of Labor Statistics estimates 325,000 in 1985 while the National Science Foundation (NSF) estimates 621,000 in 1986. Outside of psychology, according to NSF's 1986 estimates, social scientists number about 382,000 members of the labor force, including 70,000 Ph.D.s.[91] Psychologists add 240,000 to that number, including 55,000 Ph.D.s.

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[90] National Science Foundation, Science and Engineering Degrees: 1950-80. A Source Book, NSF Special Report 82-307 (Washington, DC: 1982), p. 54. Bachelor's and master's degree data for 1981-83 are from the U.S. Department of Education, National Center for Statistics, unpublished. Ph.D. data are from the National Research Council's Surveys of Earned Doctorates in the United States.

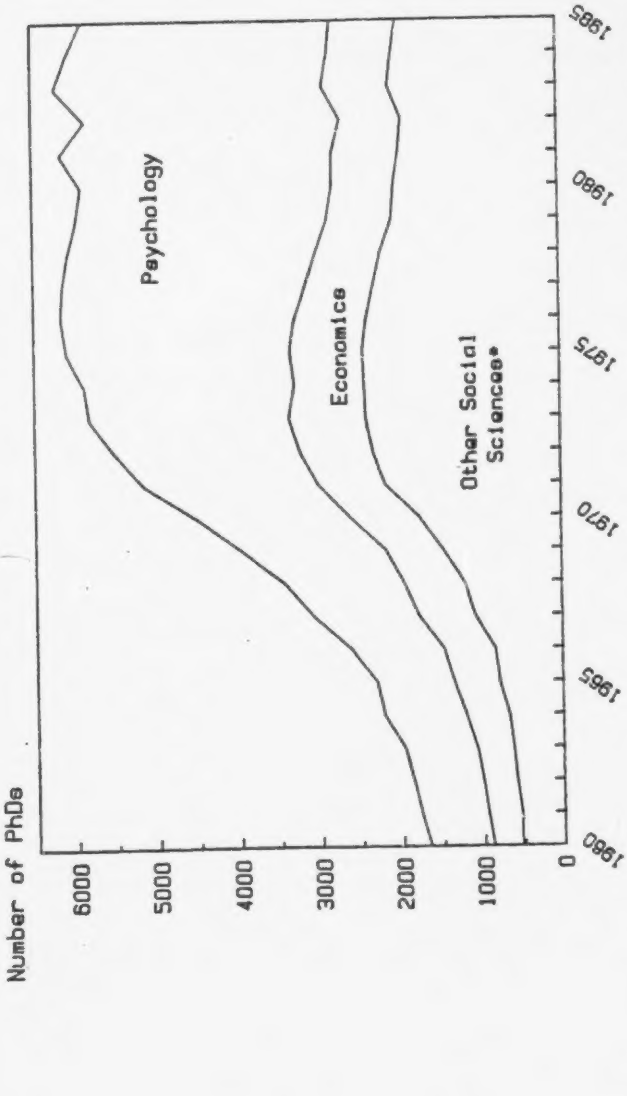
[91] National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Tables B-1 and B-11, unpublished data.

In general, social scientists are more likely to work in industry than in educational institutions, and a larger proportion work in the non-profit sector and in Federal, State, and local government compared to other sciences. Unemployment is traditionally higher among social and behavioral scientists than other scientists and engineers, indicating a chronic oversupply.

The social sciences attract more women and fewer foreign students than other fields. Within specific disciplines, however, large differences exist. Psychology and economics, for example, are mirror images in terms of enrollments of women and foreign nationals. Non-Asian minorities are better represented in the social sciences than in other sciences. Indeed, the social and behavioral sciences have been viewed as fields of educational opportunity. But they, together with the life sciences, have the lowest salaries and the highest unemployment and underemployment rates. Almost one-third of the Ph.D.s trained in a social science were working outside their doctorate field in 1983. Nearly one-fifth of Ph.D.s work outside science and engineering altogether.

The market for social science Ph.D.s is still predominantly academic. This is not likely to change soon, though the more applied degrees and specialties will continue to fare better in business, industry, and state and local government.

Social/Behavioral Science PhDs
1960-1985



*includes agricultural economics

Source: National Research Council

PSYCHOLOGY

Enrollments and Degrees

- Psychology is the largest social and behavioral science field, accounting for one-half of Ph.D.s and one-third of bachelor's degrees in social sciences. Although Ph.D.s in the social sciences have declined since 1976, Ph.D.s in psychology have continued at about 3,000 per year since 1977.[92] In 1985, this number represented 16 percent of the doctorates granted in all science and engineering.
- Current graduate enrollments in doctoral degree programs are about 60 percent in clinical specialties, 40 percent in research and experimental specialties.[93]
- Bachelor's graduates in psychology are more likely than other social scientists to complete one or more graduate degrees.

Employment Patterns

- There are 170,000 to 240,000 psychologists employed in the United States. Of these, three out of four are employed in science and engineering (S/E) positions.[94]
- In 1986, over 20 percent of psychologists in S/E positions are employed in business and industry; another 20 percent work in nonprofit organizations, and almost one-half in academia.[95]
- The work of psychologists in S/E positions differs from those of other S/E professionals. Only 9 percent of psychologists are engaged in research and

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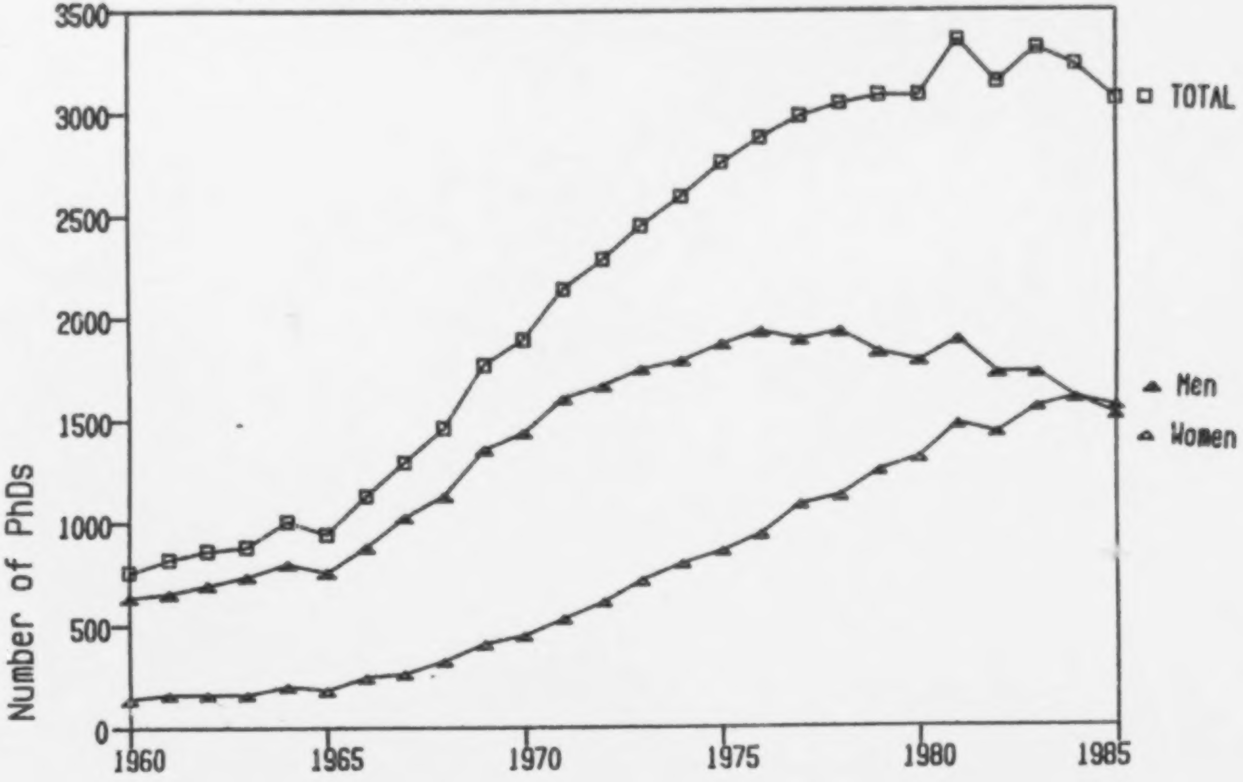
[92] National Science Foundation, Science and Engineering Doctorates: 1960-82, NSF 83-328 (Washington, DC: no date), p. 19, Table 1.

[93] Georgine M. Pion, et al., Summary Report of the 1984-85 Survey of Graduate Departments of Psychology (Washington, DC: American Psychological Association, June 1985), p. 28, Table 11.

[94] The Bureau of Labor Statistics reports 169,000 employed psychologists in 1985; the National Science Foundation estimates 239,700 in 1986. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Table B-1.

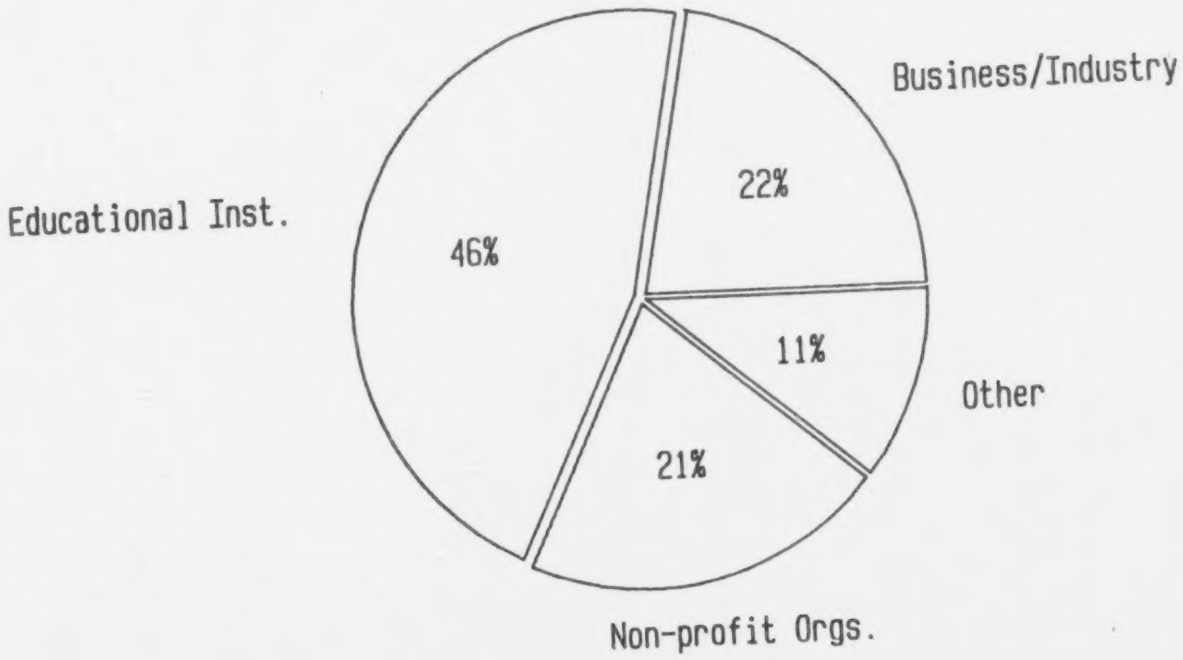
[95] Ibid., Table B-13.

Psychology PhDs, By Sex, 1960-1985



Source: NRC

Where Psychologists Work, 1986



SOURCE: NATIONAL SCIENCE FOUNDATION

development, 22 percent in teaching, and 17 percent in some type of management.[96] Part of this may be explained by the large numbers of psychologists in clinical practice.

- Compared to other doctoral-level scientists, psychologists exhibit relatively low mobility into other scientific fields.[97] Instead, they may move out of science altogether in times of oversupply, as indicated by the high proportion of psychology Ph.D.s reporting non-science/ engineering employment.
- Psychologists generally follow two career paths. Clinical psychologists, with a bachelor's or master's, work in industry or hospitals and other health service occupations. Two-thirds of clinical psychologists are bachelor's or master's holders. Experimental psychologists earn a Ph.D. and enter academic research, or, to a lesser extent, industry; three out of four of psychologists active in research hold a Ph.D.[98]
- Between 1972 and 1984, subfields associated with academic research — experimental, comparative, and physiological — declined while clinical specialties thrived. Over half of recent Ph.D.s in psychology have been awarded in clinical subfields, and new Ph.D.s increasingly enter private or public clinical practice (health service provider) instead of pursuing traditional academic careers.[99]

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[96] Ibid.

[97] National Research Council, Office of Scientific and Engineering Personnel, Science, Engineering, and Humanities Doctorates in the United States: 1983 Profile (Washington, DC: National Academy Press, 1985), pp. 18-19, Table 2-2.

[98] Joy Stapp, et al., "Census of Psychological Personnel: 1983," American Psychologist, vol. 40, No. 12, December 1985, pp. 1,334-1,341.

[99] Georgine M. Pion and Mark W. Lipsey, "Psychology and Society: The Challenge of Change," American Psychologist, vol. 39, No. 7, July 1984, pp. 739-754; and Ann Howard, et al., "The Changing Face of American Psychology: A Report from the Committee on Employment and Human Resources," unpublished manuscript.

Women, Minorities, and Foreign Nationals

- The composition of the psychology degree pool is distinctive: women dominate at the bachelor's level (two of every three bachelor's awarded) and earn half of the Ph.D.s, the highest proportion among the sciences.[100] Women tend to congregate in developmental, educational, and clinical psychology, while men hold more research positions.
- Despite receiving a majority of psychology degrees, women are less likely to be tenured or on a tenure track, and more likely to be working part-time. In graduate departments of psychology, two-thirds of the faculty are male.
- Minority participation in psychology is very low: 3 to 6 percent black, 3 percent Hispanic, and 1 percent Asian and Native American.
- There are very few foreign nationals in psychology; they comprise only 4 percent of current graduate enrollment, compared to 20 percent for other social sciences.[101]

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[100] Commission on Professionals in Science and Technology, Professional Women and Minorities: A Manpower Data Resource Science, 6th Edition (Washington, DC: February 1986), pp. 232, 241-242.

[101] National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983, NSF 85-300 (Washington, DC: 1985), p. 27, Table A-8.

ECONOMICS

Education and Supply

- For 25 years economics has attracted many students. Baccalaureate production more than doubled to 17,000 in 1970, declined slightly to mid-decade, and has climbed ever since, surpassing 20,000 in 1983.
- Master's degrees exhibit a similar pattern to baccalaureates, plateauing in 1980 around 2,000 and holding stable. Ph.D. production has fluctuated between 700 and 800 a year since 1970.[102]

Employment Patterns

- There are 111,000 to 145,500 economists employed in the United States. Of these, three out of five are employed in science and engineering (S/E) positions.[103]
- In 1986, 42 percent of the economists holding S/E positions are working in business and industry, 35 percent in academe and 12 percent in the Federal Government.[104] In the last decade, economists have doubled their number in the work force.
- The principal work activity of S/E economists in 1986 is management/administration (25 percent), followed by teaching (24 percent), and research and development (19 percent).[105]
- The profile for the 20,000 Ph.D. economists in the work force is more academic, with almost half having teaching as their primary work activity and one quarter engaged in R&D.[106]

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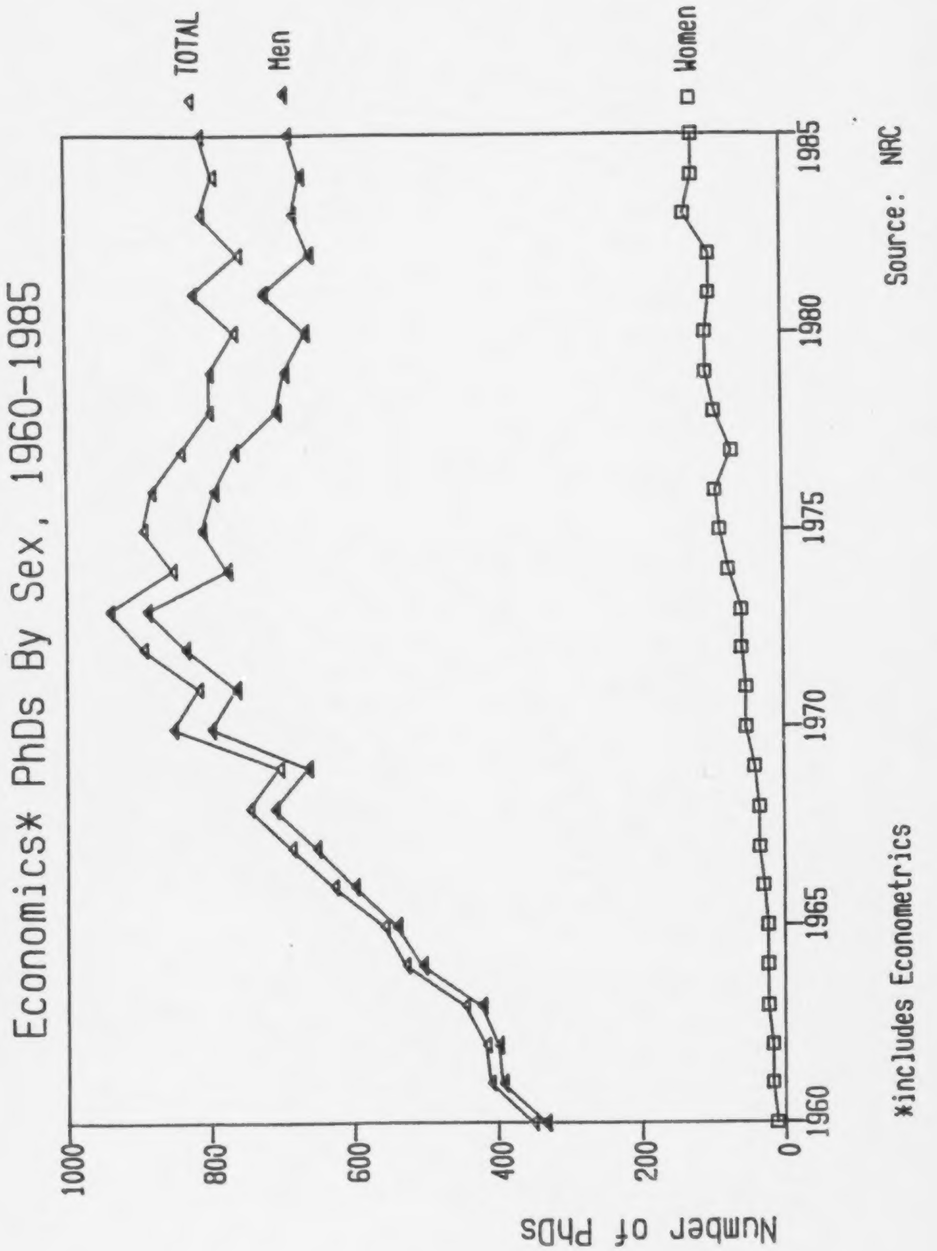
[102] National Science Foundation, Science and Engineering Degrees: 1950-80. A Source Book, NSF 82-307 (Washington, DC: 1982), p. 56.

[103] The Bureau of Labor Statistics reported 110,000 employed economists in 1985; the National Science Foundation estimates 145,500 in 1986. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Table B-1, unpublished data.

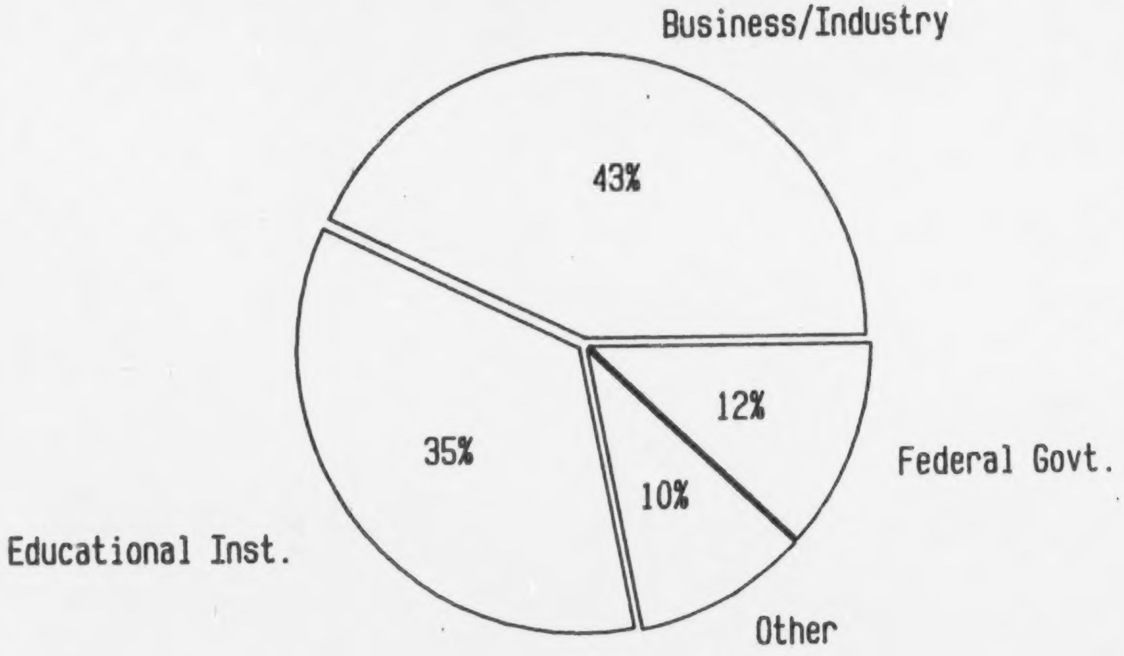
[104] National Science Foundation, Science Resources Studies Division, op. cit.

[105] Ibid.

[106] National Science Foundation, Science and Engineering Personnel: A National Overview, NSF 85-302 (Washington, DC: 1985), pp. 117, 121, 125, 129, Table 12-b, and unpublished data 1986 estimates.


Economics* PhDs By Sex, 1960-1985
Number of PhDs
1000
800
600
400
200
0
1960
1965
1970
1975
1980
1985
TOTAL
Men
Women
*includes Econometrics
Source: NRC

Where Economists Work, 1986



SOURCE: NATIONAL SCIENCE FOUNDATION

- The average salary for a Ph.D. economist in 1983 was $42,000. This exceeds the average for scientists/engineers in all fields combined by almost $3,000 and in social sciences by $6,000.[107] Although new job openings were down in 1985 from the year before, the academic market has accommodated new Ph.D.s seeking entry-level positions.[108]

Women, Minorities, and Foreign Nationals

- Women have historically fared poorly in economics. They receive disproportionately fewer of the degrees awarded at all levels, 33 percent of bachelor's, 24 percent of master's, and 16 percent of Ph.D.s. Women have slowly increased their share of degrees over the past decade, although this increase has slowed. According to one survey, the percentage of female economics assistant professors doubled to 16 percent between 1976 and 1984. Still, in that year only 4 percent of the tenured economics faculty were women.[109]
- Blacks and Hispanics are not well represented in economics, while Asians are doing somewhat better. In 1983, black economists in the work force totaled 3 percent, Asians 7 percent, and Hispanics 2 percent. Black economists have remained between 1 and 2 percent of Ph.D.s since 1973, while Asians have doubled their participation to 9 percent. Ph.D. data for 1985 show this trend continuing: blacks, Hispanics, and American Indians combined account for less than 4 percent of the doctorates granted.[110]

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[107] Ibid., p. 140, Table B-18.

[108] C. Elton Hinshaw, "Report of the Director: Job Openings for Economists," in Proceedings of the 98th Meeting of the American Economic Association, American Economic Review, vol. 76, No. 2, May 1986, pp. 443-444.

[109] Isabell Sawhill, "Report of the Committee on the Status of Women in the Economics Profession," in Proceedings of the 98th Meeting of the American, Economic Association, American Economic Review, vol. 76, No. 2, May 1986, pp. 452-457.

[110] National Research Council, Office of Scientific and Engineering Personnel, Doctorate Recipients from United States Universities: Summary Report 1984 (Washington, DC: National Academy Press, 1986), p. 32.

- Foreign nationals holding temporary visas are a large share of the economics talent pool. In 1960, they received 19 percent percent of the Ph.D.s conferred in economics; in 1985, that percentage was 34.[111]

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[111] Data for 1960-82 are from National Science Foundation, Science and Engineering Doctorates: 1960-1982, NSF 83-328 (Washington, DC: 1983), pp. 44-45, Table 2. Data for 1983-85 are from National Research Council, op. cit.

ENGINEERING

Overview

The engineering labor force differs markedly from the scientific labor force. This section discusses engineering as a degree and work category, then examines two engineering specialties, electrical engineering and chemical engineering.

The bachelor's is the entry-level professional degree and the one held by the vast majority of employed engineers. A master's degree or the 5-year engineer degree is an important credential, unlike most of the sciences where the master's is merely a stepping-stone to a Ph.D. or a consolation for not continuing doctorate study.

The six largest engineering specialties, in approximate rank order according to the Bureau of Labor Statistics estimates, are electrical and electronic, with over 500,000 engineers in the labor force and more than 22,000 degrees awarded in 1985, mechanical, civil, industrial, chemical, and aeronautical and aerospace. These specialties include about 80 percent of all engineers.[112]

The labor market varies considerably among engineering specialties. The market for electrical engineers may boom, while aerospace engineers are unable to find jobs. Within each engineering specialty, new skills may be in critical demand while others are

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[112] Estimates of the number of engineers employed in the United States compiled by the two major sources of labor force data, the Bureau of Labor Statistics (BLS) and the National Science Foundation (NSF), differ greatly due to differences in definition and data collection:

	BLS (1985)	**NSF (1986 est.)**
Elec	544,000	581,300
Mech	272,000	513,700
Civil	221,000	365,700
Indus	178,000	150,900
Aero	95,000	111,600
Chem	64,000	163,100
TOTAL ENGINEERS	1,683,000	2,560,600

NSF data from National Science Foundation, Science Resources Studies Division, preliminary 1986 data, Table B-1, unpublished data.

outmoded. New specialties, such as materials, bioprocess, or computer engineering, often emerge as offshoots of a traditional specialty and fall between the cracks of existing data collection, making it difficult to track their progress.

Industrial requirements for engineers change rapidly to take advantage of new technologies or to match swings in production. To satisfy this changing demand, education of new engineers is complemented by retraining and migration (field mobility). Much of this migration occurs within the engineering population, as a growing engineering specialty draws upon others and changes the distribution among specialties. Market forces are particularly influential in the career choice of young engineers. There is a relatively stable total pool of engineers.

Education/Supply of Engineers

- Together with computer science, engineering has been the fastest growing area of study since the early 1970s. But growth has slowed as the job market settles from boom into slower growth and as the supply of 18-year-olds starts downward. The largest increase has been in bachelor's awards, which doubled between 1975 and 1985 from 38,000 to over 77,000.[113] During that same period, average growth in bachelor's awards in all fields was less than 20 percent.
- Engineering bachelor's graduates nearly doubled their share of all bachelor's degrees between 1975 and 1985, from 4.5 percent to 8 percent. The years 1984-85 mark a turning point in engineering: the slowdown in bachelor's degrees and the upswing in Ph.D.s. Master's awards continue their steady climb.

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[113] Engineering Manpower Commission, Engineering and Technology Degrees (Washington, DC: American Association of Engineering Societies, published annually). Unless otherwise noted, engineering degree data are from the Engineering Manpower Commission. The Commission data at all degree levels tend to be slightly higher than data reported by the National Research Council and the U.S. Department of Education's National Center for Statistics, but follow a similar pattern.

- The unprecedented surge in undergraduate engineering enrollments of the 1970s is settling down as college students respond to the downturn in the job market, particularly in the electronics and computer industries. Freshman enrollment started down in 1983.
- Projections based on current undergraduate enrollment levels, coupled with the declining college age population, indicate a substantial decline in the number of bachelor's engineering awards in the late 1980s, down from the 77,000 awarded in 1985 to 70,000 to 72,000 in 1989; the trend is expected to continue downward through the 1990s.[114]
- Engineering Ph.D.s, like the sciences, peaked in 1970-72 and then declined rapidly. The substantial decline in engineering Ph.D. awards relative to bachelor's awards in the 1970s testifies to the powerful influence of the attractive job market for bachelor's and master's level engineers.
- Over the past 3 years, engineering doctorate awards have increased and regained their 1975 level. Slightly over 3,100 engineering Ph.D.s were awarded in 1985.[115] Graduate enrollments have been rising since 1978, signaling a continuing increase in engineering Ph.D. awards at least into the early 1990s, up to about 4,000.
- Very few engineering students undertake postdoctoral study. There are currently about 1,200 postdoctoral students, over 60 percent of whom are foreign.

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[114] Commission on Professionals in Science and Technology, Washington, DC, unpublished data. Enrollment and degree data are from U.S. Department of Education, National Center for Statistics, freshmen intentions from Cooperative Institutional Research Program, The American Freshman: National Norms for Fall, 1985 (Los Angeles, CA: Higher Education Research Institute, December 1985).

[115] National Research Council reported 3,165 engineering Ph.D.s in 1985; Engineering Manpower Commission reported 3,383. National Research Council, Office of Scientific and Engineering Personnel, unpublished data from annual survey of doctorate recipients from United States universities, and Engineering Manpower Commission, Engineering and Technology Degrees, op. cit.

Employment/Demand for Engineers

- Engineering has been one of the fastest growing occupations in the 1980s.[116] In 1986, there are 2,560,600 engineers employed in the United States. Over 90 percent are employed in science and engineering (S/E) positions. Women make up slightly more than 3 percent of the engineering S/E work force. Only about 3 percent of employed engineers hold doctorates. About 80 percent of S/E employed engineers work in business/industry.[117]
- The labor market for an engineering specialty largely depends upon the diversity of the labor market and the economic health of key industry employers. For example, only one-third of chemical engineers work in the chemical industry, while three-quarters of aerospace engineers work in the aircraft industry.[118] Mechanical engineers work in a variety of settings, and seem able to weather business cycles by shifting to related jobs. Demand for more petroleum or nuclear engineers, on the other hand, rides the roller coaster of the energy and resource industries which dominate their market.
- Universities and colleges trying to hire faculty to handle high undergraduate enrollments face a continuing shortage of Ph.D. engineers interested in academic positions, particularly in electrical and computer engineering. Universities and colleges employ only 4 percent of all engineers, but about one-third of doctorate engineers.

Engineering Technicians and Technologists

- Engineering technicians are an important part of the engineering labor force and a source of new engineers through mobility and training.

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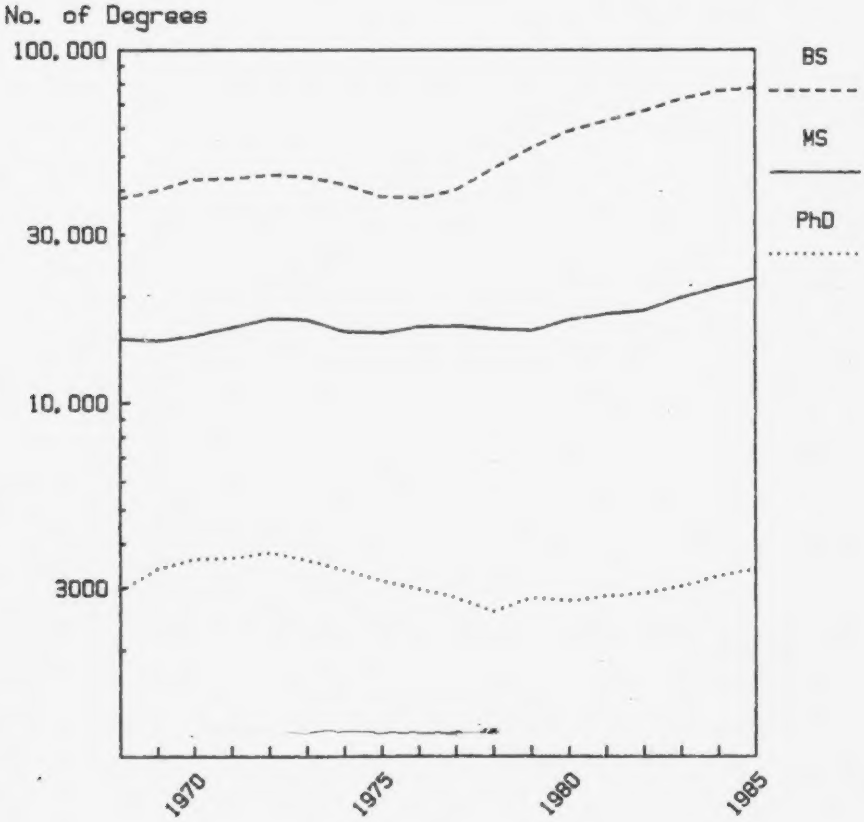
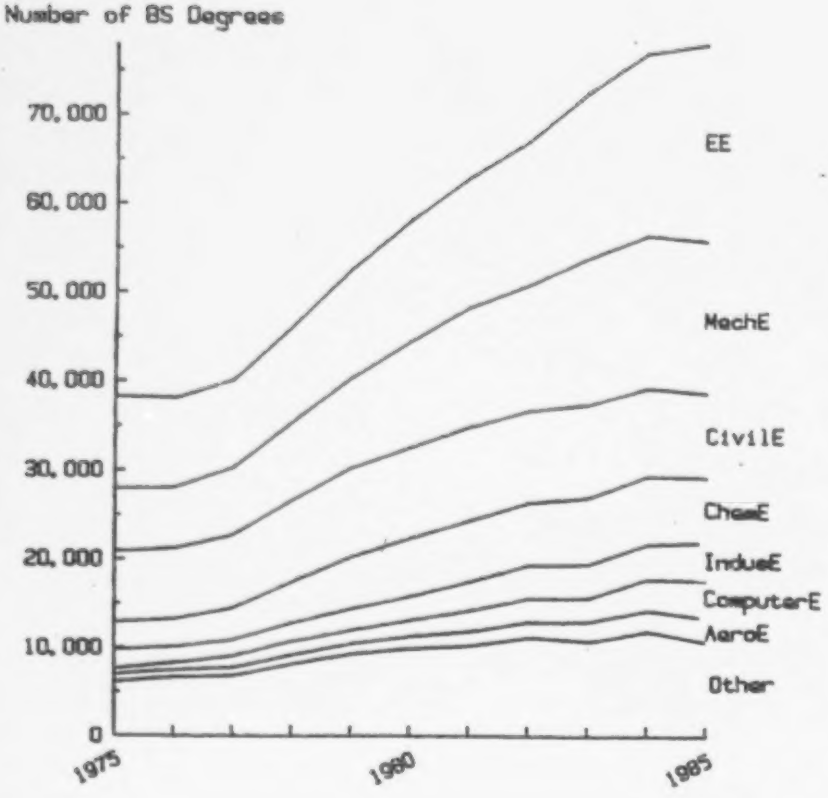
116. National Science Board, Science Indicators: The 1985 Report, NSB 85-1 (Washington, DC: National Science Foundation, 1985), p. 56.
117. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Tables B-1, B-11, B-13, unpublished data.
118. National Science Board, op. cit., p. 57.

Total Engineering Degrees, 1968-1985
BS, MS, and PhD

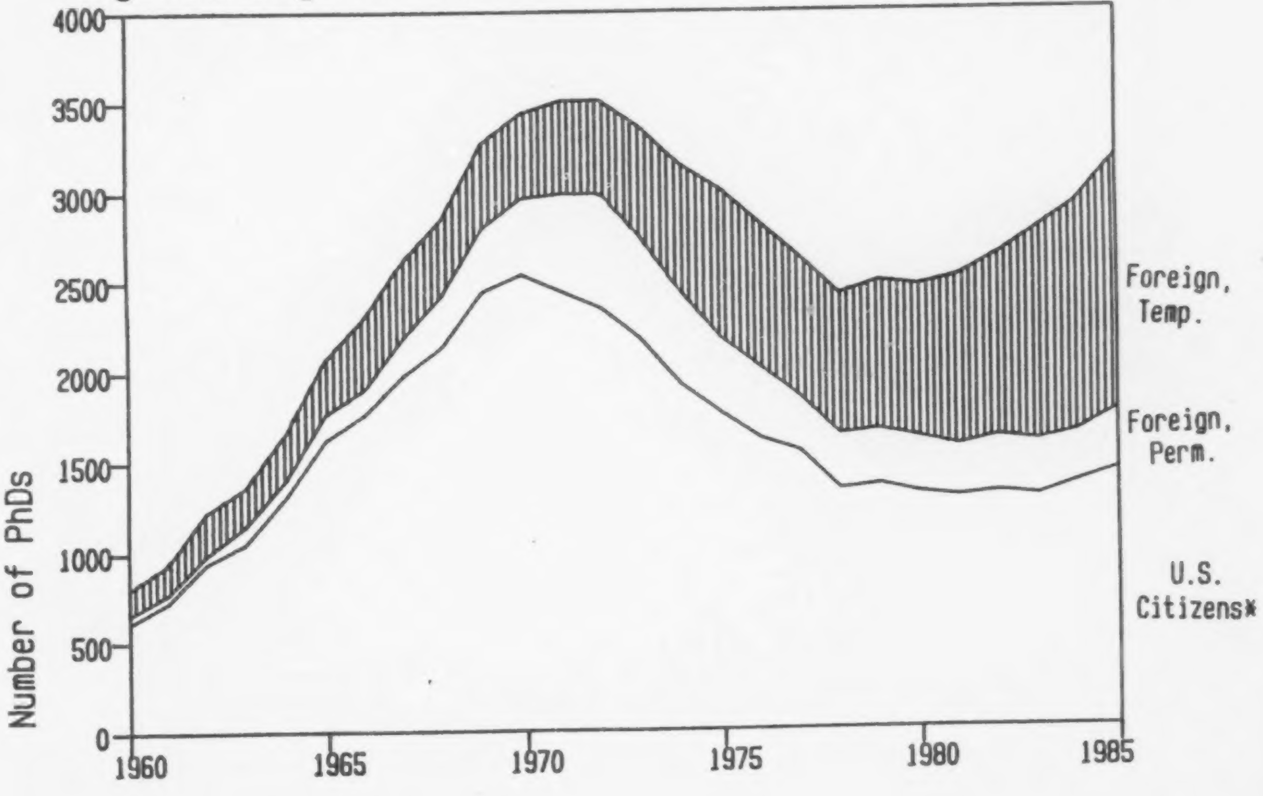


Source: Engineering Manpower Commission

BS Degrees in Engineering
1975-1985



Source: Engineering Manpower Commission

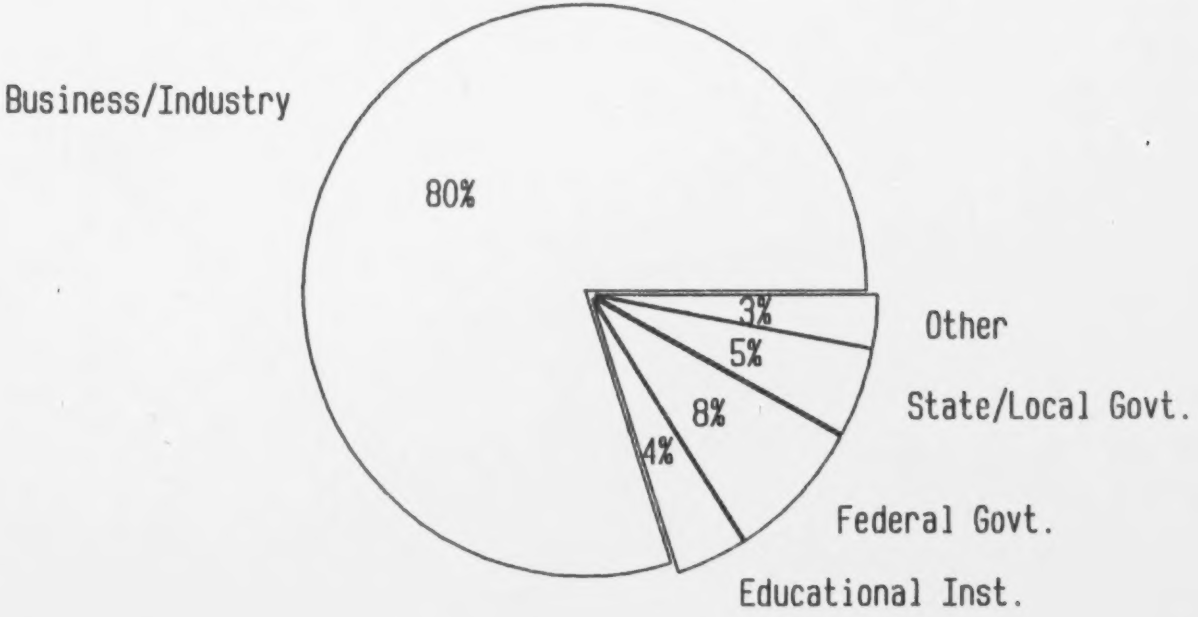


Engineering PhD Awards by Visa Status, 1960-1985

*includes unknown citizenship

Source: NRC

Where All Engineers Work, 1986



SOURCE: NATIONAL SCIENCE FOUNDATION

- There are approximately one million engineering technicians.[119] A minority are trained in 2-year and 4-year specialized engineering technician and technology programs (about 12,000 4-year bachelor's degrees and 14,000 to 20,000 2-year associate degrees were awarded in engineering technology in 1984).[120]
- Electronics and electrical technicians are by far the largest category, about 40 percent of engineering technicians and technician level degrees.[121]

Foreign Nationals

- The influx of foreign students is particularly apparent in engineering. Over 40 percent of recent engineering Ph.D.s have been awarded to foreign students on temporary visas (over 50 percent including those on permanent visas), up from 30 percent in 1975.[122]
- Forty-two percent of full-time graduate students in Ph.D.-granting institutions are foreign.[123] (They are 30 percent of all graduate students, as they are much more likely than the U.S. students to study full-time and to continue on for a Ph.D.). Foreign students have received a steady 7 to 9 percent of bachelor's engineering degrees since the mid-1970s. Their share of master's degrees increased slightly during the 1970s to 25-28 percent, which has held steady since 1980. Foreign

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[119] Betty M. Vetter and Eleanor L. Babco, Professional Women and Minorities: A Manpower Data Resource Service, 5th Edition (Washington, DC: Scientific Manpower Commission, August 1984), p. 198, Table 7-31.

[120] Ibid., p. 192, Table 7-25. Unpublished data for 1984 furnished by Betty Vetter.

[121] Estimates of engineering technician population provided by Betty Vetter, Scientific Manpower Commission, based on the Bureau of Labor Statistics data and the Engineering Manpower Commission's Engineering and Technology Degrees series. Vetter estimates 384,000 electrical/electronic technicians out of 984,000 total in 1985. Department of Education's National Center for Science unpublished data on engineering technology/technician degrees is significantly higher than Engineering Manpower Commission data.

[122] National Science Foundation, Science and Engineering Doctorates: 1960-82, NSF 83-328 (Washington, DC: no date), pp. 30-31, 42-43, Table 2.

[123] National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983, NSF 85-300 (Washington, DC: 1985), p. 28, Table A-9.

engineering students are particularly important at the graduate level due to the paucity of American graduate students.

- The high demand for engineers has made it easier for foreign students to study and work in the United States. In particular, the shortage of academic engineering faculty has made university and college departments particularly dependent on foreign Ph.D.s.
- About half of graduating foreign engineers stay on to work in the United States, at all degree levels. When those with permanent visas are included, the percentage rises to over 60 percent.[124] Foreign engineering students are much more likely to hold temporary visas than foreign science students; all of the increase in engineering Ph.D. awards has been due to foreign students on temporary visas.
- About 70 percent of the foreign students who receive engineering Ph.D.s are Asian,[125] and over 90 percent of American-Asian Ph.D. scientists and engineers are foreign born.[126]

Women and Minorities

- Women have shared in the engineering boom but their enrollment and degree-taking is now leveling off after a decade of rapid growth. In 1985, women received 6 percent of engineering Ph.D.s, 11 percent of Master's degrees, and 15 percent of bachelor's degrees.
- Women make up 3-6 percent of the engineering labor force.[127] Women engineers

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[124] Oak Ridge Associated Universities, Labor and Policy Studies Program, Foreign National Scientists and Engineers in the Labor Force, 1972-1982, ORAU-244 (Oak Ridge, TN: June 1985), p. 5.

[125] National Science Foundation, Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook (Washington, DC: 1985), p. xiii.

[126] National Research Council, Office of Scientific and Engineering Personnel, unpublished data from 1985 survey of doctorate recipients from U.S. universities.

[127] The National Science Foundation estimates 3.3 percent in 1984, the Bureau of Labor Statistics reports 6.7 percent in 1985. National Science Foundation, U.S. Scientists and Engineers: 1984, op. cit., p. 37, Table B-1.

tend to concentrate in certain subfields, particularly chemical, petroleum, and industrial engineering, and are less likely to choose electrical and computer engineering. Their greatest increase has been in mechanical engineering.

- The slow inroads of blacks and Hispanics into engineering have stalled. The attrition rate for blacks and Hispanics is much higher than for whites or Asians; about half of Hispanics and just one-third of blacks among engineering freshmen successfully complete an undergraduate engineering program, compared to an average for all freshmen of 70 percent.
- Blacks are about 2 percent of all employed engineers.[128] Together, blacks, Hispanics, and Native Americans are about 5 percent of engineers. Asian-Americans are an additional 7 percent.
- Minorities are particularly underrepresented at the Ph.D. level in comparison to the sciences. Between 1958 and 1983, blacks received 0.5 percent of engineering Ph.D.s. Of 1985 bachelor's engineering degrees, less than 3 percent went to blacks, and less than 4 percent to Hispanics and over 5 percent to Asians.
- Asians are doing well in engineering. They received over 5 percent of the bachelor's and over 7 percent of the Ph.D. degrees awarded in engineering in 1985. Most of these degree recipients, however, are foreign-born Asian immigrants.

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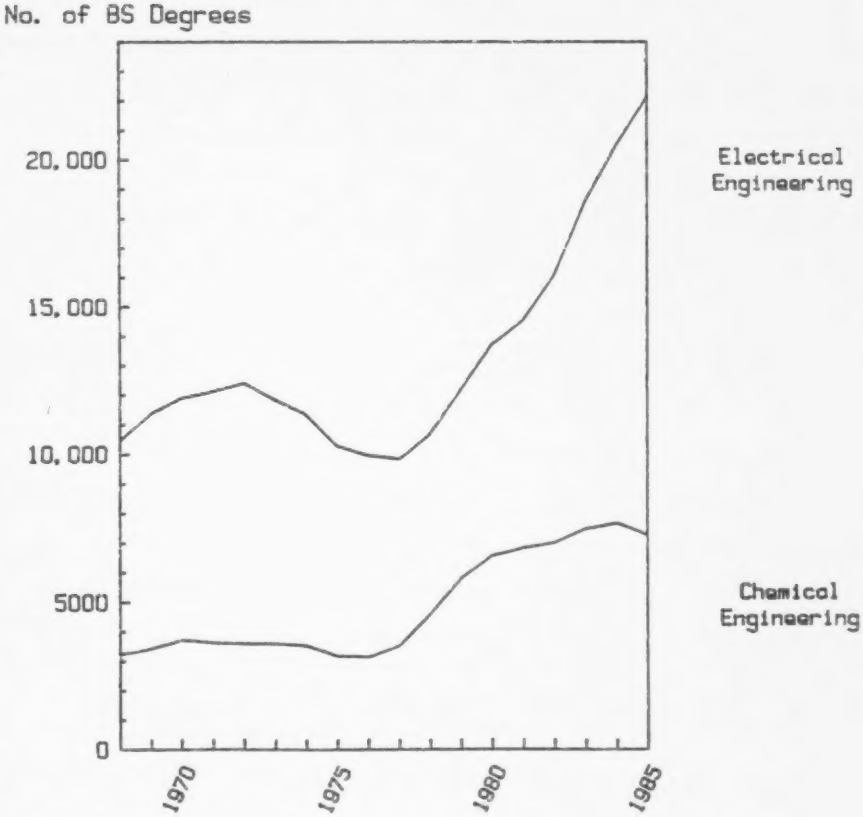
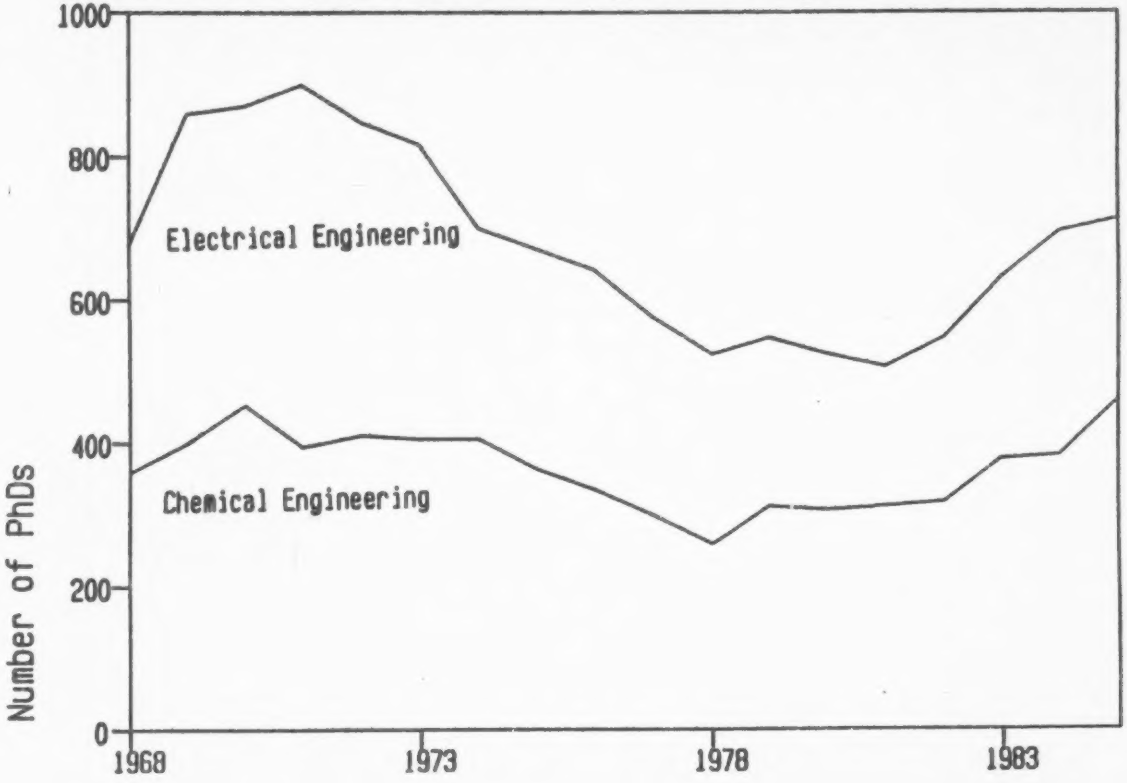
[128] National Science Foundation estimates 1.8 percent in 1986, the Bureau of Labor Statistics reports 2.6 percent in 1985. Ibid., p. 42, Table B-2.

Engineering BS Degrees, 1968-1985



Source: Engineering Manpower Commission

Electrical & Chemical Engineering PhDs, 1968-1985



Source: EMC

CHEMICAL ENGINEERING

Supply and Demand

- There are 64,000 to 163,000 chemical engineers employed in the United States. Of these, over 90 percent, are employed in science and engineering (S/E) positions. Women make up about 7 percent of the chemical engineering S/E work force. Over 90 percent of the S/E chemical engineers work in business and industry, mostly in industries related to chemical production and petroleum refining.[129] Consequently, the job market fluctuates with the business cycles of the petroleum industry.
- Currently there is an excess of chemical engineers, particularly at the bachelor's level, where unemployment is among the highest for recently graduated engineers. Changes in industry R&D priorities have generated the current surplus of petrochemical engineers and shortage of biochemical/bioprocess engineers.
- Undergraduate interest in chemical engineering tracks the current job market, with a 4-year lag in degrees. The 7,300 bachelor's degrees awarded in 1985 is down from 1984, following a steady increase through the 1970s and early 1980s. Master's degrees were awarded to 1,600 in 1985, continuing a slow increase. Ph.D. awards have increased slowly since 1980, to 460 in 1985. Dauffenbach and Fiorito project a small rise in chemical engineering bachelor's degrees by 1995, and faster increases in master's and Ph.D. degrees.[130]

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[129] The Bureau of Labor Statistics reported 156,000 chemical engineers in 1985; the National Science Foundation estimates 163,100 chemical engineers employed in the United States for 1986. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Tables B-1 and B-13, unpublished data.

[130] Robert C. Dauffenbach and Jack Fiorito, The Engineering Degree Conferral Process: Analysis, Monitoring, and Projections (Washington, DC: Engineering Manpower Commission, November 1984), p. 58, Table IV-1.

- Chemical engineers (and petroleum engineers) are twice as likely as other engineers to go on for a Ph.D. and are the most likely to do postdoctoral research. This may in part be due to the relatively more research and development (R&D)-intensive, centralized structure of the chemical industry, their major employer.
- There are about 7,000 employed Ph.D. chemical engineers, about 40 percent in R&D. They and petroleum engineers are the highest paid engineers. Most Ph.D.s still go into industry rather than academia — two-thirds are in industry, one quarter in universities and colleges, 3 percent in nonprofit institutions, and 2.5 percent Federally employed.[131]

Women, Minorities, and Foreign Nationals

- Chemical engineering has long been one of the most fruitful engineering specialties for women. Women now earn over a quarter of bachelor's chemical engineering degrees, 11 percent of master's degrees, and 6 percent of Ph.D.s.[132] They are 15 percent of graduate students and about 6 percent of chemical engineers in universities and colleges.
- Minority representation in chemical engineering is typical: among bachelor's recipients, 3 percent are black, 1-2 percent Hispanic, and 5 percent Asian.[133]
- Chemical engineering attracts relatively few foreign students; they earn about 5 percent of bachelor's chemical engineering degrees, a proportion that exceeded 8 percent in 1976.
- Chemical engineering is the only engineering specialty where foreign nationals have steadily decreased as a proportion of full-time graduate enrollments (since

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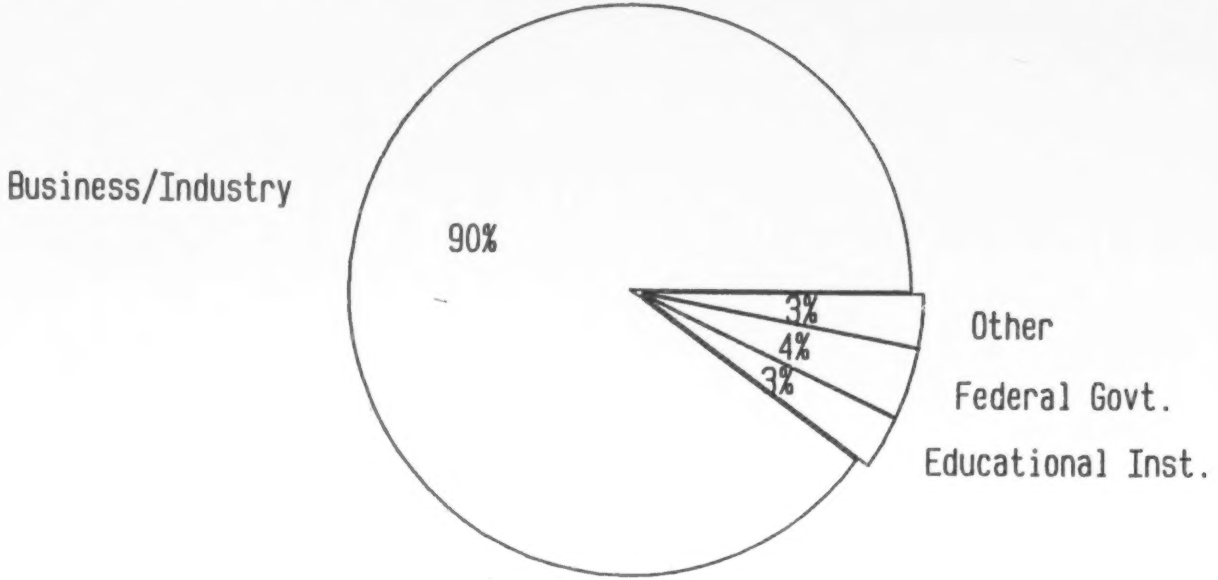
131. National Science Foundation, Characteristics of Doctoral Scientists and Engineers in the United States, NSF 85-303 (Washington, DC: 1985), p. 22, Table B-5.
132. Engineering Manpower Commission, Engineering and Technology Degrees (Washington, DC: American Association of Engineering Societies, published annually).
133. Ibid.

Where Chemical Engineers Work, 1986



Source: National Science Foundation

1977).[134] However, the most recent National Science Foundation estimates show an increase in the proportion of foreign full-time graduate students to 40 percent.

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[134] National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983, NSF 85-300 (Washington, DC: 1985), pp. 104, 130-31, Tables C-6, C-27, C-28.

ELECTRICAL ENGINEERING

Supply and Demand

- Electrical and electronic engineering is the largest engineering specialty. In 1986, there are 580,000 electrical and electronic engineers employed in the United States. According to the National Science Foundation, of these, 95 percent are working in science and engineering (S/E) positions with over 80 percent employed in business and industry, primarily the electronics and computer industries. Women make up 2 percent of the electrical and electronic engineering work force. About 3 percent of all employed electrical and electronic engineers hold Ph.D. degrees.[135]
- Slightly more than one-quarter of all engineering bachelor's degrees and slightly less than one-quarter of all engineering Ph.D.s are in electrical engineering.[136]
- High industrial demand and high salaries spurred a doubling of bachelor's awards in electrical engineering between 1975 and 1985, from 10,000 to 22,000. master's awards have slowly increased since 1979 to 5,500. Following the engineering-wide decline in Ph.D. awards through the 1970s, electrical engineering Ph.D. awards did not begin to increase until 1981, in great part because of the high demand for bachelor's electrical engineers.
- Dauffenbach and Fiorito project a 65 percent increases in bachelor's awards and 20 percent increase in Ph.D.s by 1995 due to continued expansion of computer and electronics applications in all industries.[137]

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135. National Science Foundation, Science Resources Studies Division, preliminary 1986 estimates, Tables B-1, B-11, and B-13, unpublished data.
136. Engineering Manpower Commission, Engineering and Technology Degrees (Washington, DC: American Association of Engineering Societies, published annually).
137. Robert C. Dauffenbach and Jack Fiorito, The Engineering Degree Conferral Process: Analysis, Monitoring, and Projections (Washington, DC: Engineering Manpower Commission, November 1984), p. 58, Table IV-1.

- Electrical engineering is a bachelor's level field. Of the over one-half million employed electrical engineers, less than 5 percent have a Ph.D. Those who do earn a Ph.D. are more likely to go into academic teaching than are chemical engineers. Most Ph.D.s, however, still go into industry.[138]

Foreign Nationals, Minorities, and Women

- The vigorous worldwide computer and electronics market has attracted many foreign students to enroll in U.S. electrical engineering programs. Foreign students have earned 8 to 9 percent of bachelor's electrical engineering degrees since 1980 and nearly half of Ph.D.s. Electrical and computer engineering host the fastest growing number of foreign students.
- Asian-Americans have been particularly successful in electrical engineering, while other minorities lag behind. Blacks and Hispanics each earn a constant 3 percent of bachelor's degrees, while Asians have increased their share to over 8 percent of bachelor's awards. Among graduate students, Asians outnumber both blacks and Hispanics by four to one.
- Women have slowly but surely made their way into electrical engineering. They earn about 10 percent of the bachelor's degrees, but account for only 2 percent of the employment in electrical engineering.

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[138] National Science Foundation, Characteristics of Doctoral Scientists and Engineers in the United States, NSF 85-303 (Washington, DC: 1985), p. 22, Table B-5.

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